PB90-195777

Economic Assessment Environmental Impact Statement. NESHAPS (National Emission Standards for Hazardous Air Pollutants) for Radionuclides. Background Information Document. Volume 3

(U.S.) Office of Radiation Programs, Washington, DC

Sep 89

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA 520/1-89-007

2.

3. RECIPIENT'S ACCESSION NO.
PB90 195777/AS

4. TITLE AND SUBTITLE
Economic Assessment EIS - NESHAPS for Radionuclides
Vol. 3

5. REPORT DATE
September 1989

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Office of Radiation Programs

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Environmental Protection Agency
Office of Radiation Programs
401 M Street, SW
Washington, DC 20460

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This document has chapters on each radionuclide source category studies. Each chapter includes an introduction, industry profile, summary of emissions, risk levels, the benefits and costs of emission controls, and exonomic impact evaluations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Radionuclides	Category		
Radiation	Emissions		
Exposure			
Economics			
Cost			
Risk			
Assessment			

18. DISTRIBUTION STATEMENT
Release Unlimited

19. SECURITY CLASS *(This Report)*
unclassified

20. SECURITY CLASS *(This page)*

21. NO. OF PAGES
516

22. PRICE
A23

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

INSTRUCTIONS

1. **REPORT NUMBER**
   Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
   Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
   Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
   Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approval, date of preparation, etc.)*.

6. **PERFORMING ORGANIZATION CODE**
   Leave blank.

7. **AUTHOR(S)**
   Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
   Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
   Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
    Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
    Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
    Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
    Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
    Insert appropriate code.

15. **SUPPLEMENTARY NOTES**
    Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
    Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
    (a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

    (b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

    (c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
    Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. SECURITY CLASSIFICATION
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
    Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
    Insert the price set by the National Technical Information Service or the Government Printing Office, if known.

United States
Environmental Protection
Agency

Office of Radiation Programs
(ANR-459)

EPA/520/1-89-007
September 1989

PB90-195777

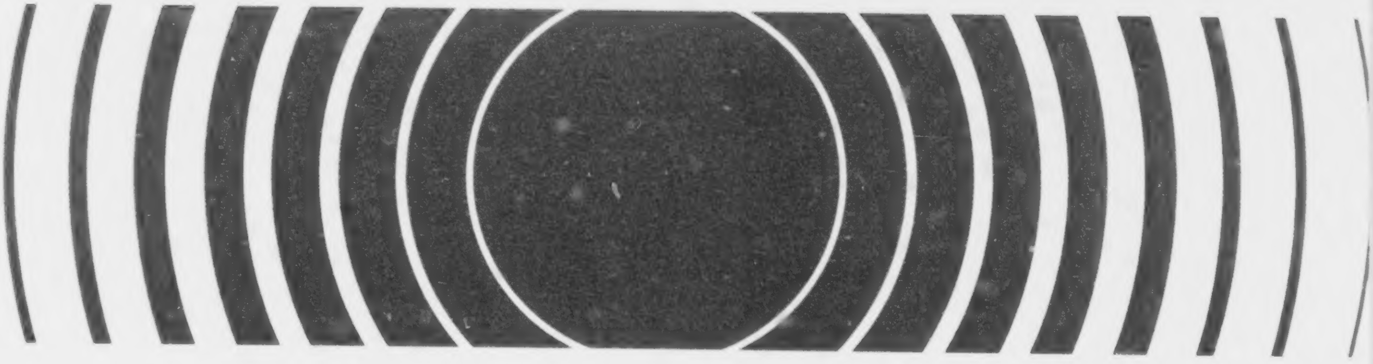
EPA

Economic Assessment

Environmental Impact Statement

NESHAPS for Radionuclides

Background Information Document — Volume 3



REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

Printed on Recycled Paper

40 CFR Part 61
National Emission Standards
for Hazardous Air Pollutants

EPA 520/1-89-007

Economic Assessment

Environmental Impact Statement for NESHAPS Radionuclides

VOLUME 3

BACKGROUND INFORMATION DOCUMENT

September 1989
U.S. Environmental Protection Agency
Office of Radiation Programs
Washington, D.C. 20460

Preface

The Environmental Protection Agency is promulgating National Emission Standards for Hazardous Air Pollutants (NESHAPs) for Radionuclides. An Environmental Impact Statement (EIS) has been prepared in support of the rulemaking. The EIS consists of the following three volumes:

VOLUME I - Risk Assessment Methodology

This document contains chapters on hazard identification, movement of radionuclides through environmental pathways, radiation dosimetry, estimating the risk of health effects resulting from expose to low levels of ionizing radiation, and a summary of the uncertainties in calculations of dose and risks.

VOLUME II - Risk Assessments

This document contains a chapter on each radionuclide source category studied. The chapters include an introduction, category description, process description, control technology, health impact assessment, supplemental control technology, and cost. It has an appendix which contains the inputs to all the computer runs used to generate the risk assessment.

VOLUME III - Economic Assessment

This document has chapters on each radionuclide source category studied. Each chapter includes an introduction, industry profile, summary of emissions, risk levels, the benefits and costs of emission controls, and economic impact evaluations.

Copies of the EIS in whole or in part are available to all interested persons; an announcement of the availability appears in the Federal Register. For additional information, contact James Hardin at (202) 475-9610 or write to:

Director, Criteria and Standards Division
Office of Radiation Programs (ANR-460)
Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

LIST OF PREPARERS

Various staff members from EPA's Office of Radiation Programs contributed in the development and preparation of the EIS.

Terrence McLaughlin	Chief, Environmental Standards Branch	
James Hardin	Health Physicist	Project Officer
Byron Bunger	Economist	Author/Reviewer
Fran Cohen	Attorney Advisor	Reviewer
Albert Colli	Environmental Scientist	Author/Reviewer
Larry Gray	Environmental Scientist	Author/Reviewer
W. Daniel Hendricks	Environmental Scientist	Reviewer
Paul Magno	Environmental Scientist	Author/Reviewer
Christopher B. Nelson	Environmental Scientist	Author
Dr. Neal S. Nelson	Radiobiologist	Author
Barry Parks	Health Physicist	Reviewer
Dr. Jerome Pushkin	Chief Bioeffects Analysis Branch	Author/Reviewer
Jack L. Russell	Engineer	Author/Reviewer
Dr. James T. Walker	Radiation Biophysicist	Author
Larry Weinstock	Attorney Advisor	Reviewer

An EPA contractor, S. Cohen and Associates, Inc., McLean, VA, provided significant technical support in the preparation of the EIS.

INTRODUCTION

The purpose of this report is to analyze the economic factors affecting the regulation of radionuclides in the twelve categories listed below. For each category, the industry was profiled and analyses regarding the cost of applying the controls suggested in the Volume II of the Background Information Document, the cost effectiveness of the controls, and their effect on production costs and on regional and local economies were performed.

The categories considered were:

1. The Uranium Fuel Cycle Facilities
2. Underground Uranium Mines
3. Inactive Uranium Mill Tailings
4. Licensed Uranium Mill Tailings
5. High-Level Waste Disposal Facilities
6. Department of Energy Facilities
7. Department of Energy Radon Facilities
8. Elemental Phosphorus
9. Phosphogypsum Stacks
10. Coal Fired Boilers
11. Nuclear Regulatory Commission Licensed and non-DOE Federal Facilities
12. Surface Uranium Mines

The data regarding the control options was developed for Volume II and was incorporated into the economic analysis. Other economic data was gathered from public available information.

TABLE OF CONTENTS

Page

PREFACE iii
LIST OF PREPARERS v
INTRODUCTION vii
TABLE OF CONTENTS ix
LIST OF TABLES xviii
LIST OF FIGURES xxix
1. URANIUM FUEL CYCLE FACILITIES 1-1
1.1 Introduction and Summary 1-1
1.2 Industry Profile 1-2
1.2.1 Introduction 1-2
1.2.2 Uranium Mills 1-2
1.2.3 Uranium Conversion Facilities 1-2
1.2.4 Fuel Fabrication Facilities 1-5
1.2.5 Light Water Power Reactors 1-5
1.3 Current Emissions, Risk Levels, and Feasible Controls Methods 1-5
1.3.1 Introduction 1-5
1.3.2 Current Emissions and Estimated Risk Levels 1-7
1.3.2.1 Uranium Mills 1-7
1.3.2.2 Uranium Fuel Conversion Facilities 1-9
1.3.2.3 Uranium Fuel Fabrication Facilities 1-9
1.3.2.4 Nuclear Power Reactors 1-13
1.3.3 Control Technologies 1-13
1.3.3.1 Uranium Mills 1-13
1.3.3.2 Uranium Conversion Facilities 1-15
1.3.3.3 Uranium Fuel Fabrication Facilities 1-15
1.3.3.4 Nuclear Power Reactors 1-15
1.4 Industry Cost and Economic Impact Analysis 1-16
REFERENCES 1-17
2. UNDERGROUND URANIUM MINES 2-1
2.1 Introduction 2-1

TABLE OF CONTENTS

Page

2.2 Industry Profile . . . 2-1
  2.2.1 Demand . . . 2-1
  2.2.2 Sources of Supply . . . 2-2
    2.2.2.1 Domestic Production . . . 2-2
    2.2.2.2 Imports . . . 2-3
    2.2.2.3 Inventories . . . 2-3
    2.2.2.4 Secondary Market Transactions . . . 2-3
  2.2.3 Financial Analysis . . . 2-4
    2.2.3.1 Homestake Mining Company . . . 2-4
    2.2.3.2 Rio Algom . . . 2-5
    2.2.3.3 Plateau Resources Limited . . . 2-5
    2.2.3.4 Western Nuclear . . . 2-5
  2.2.4 Industry Forecast and Outlook . . . 2-6
    2.2.4.1 Projections of Domestic Production . . . 2-6
    2.2.4.2 Near-Term Projections . . . 2-7

2.3 Current Emissions, Risk Levels, and Feasible Control Methods . . . 2-8
  2.3.1 Introduction . . . 2-8
  2.3.2 Current Emissions and Estimated Risk Levels . . . 2-8
  2.3.3 Control Technologies . . . 2-8
    2.3.3.1 Introduction . . . 2-8
    2.3.3.2 Alternative One . . . 2-11
    2.3.3.3 Alternative Two . . . 2-13

2.4 Analysis of Benefits and Costs . . . 2-13
  2.4.1 Introduction . . . 2-13
  2.4.2 Least-Cost Control Technologies . . . 2-13
  2.4.3 Benefits of Control Alternatives . . . 2-21
  2.4.4 Costs of Control Alternatives . . . 2-21
  2.4.5 Sensitivity Analysis . . . 2-21

2.5 Industry Cost and Economic Impact Analysis . . . 2-28
  2.5.1 Introduction . . . 2-28
  2.5.2 Production Cost Impacts . . . 2-28
  2.5.3 Economic Impact Analysis . . . 2-28
  2.5.4 Regulatory Flexibility Analysis . . . 2-30

REFERENCES . . . 2-31

3. INACTIVE MILL TAILINGS . . . 3-1

3.1 Introduction and Summary . . . 3-1
  3.1.1 Rulemaking History and Current Regulations . . . 3-1

3.2 Inactive Industry Profile . . . 3-3
  3.2.1 Current Status of Inactive Mills . . . 3-3
  3.2.2 Use of Inactive Mill Sites . . . 3-3

3.3 Current Emissions, Risks, and Control Methods . . . 3-5

TABLE OF CONTENTS

Page

3.3.1 Current Emissions and Estimated Risk Levels 3-6
3.3.1.1 Development of the Radon Source Terms 3-6
3.3.1.2 Demographic and Meteorological Data 3-6
3.3.1.3 Exposures and Risks to Nearby Individuals 3-8
3.3.1.4 Exposures and Risks to the Regional Population 3-8
3.3.1.5 Exposures and Risks under Alternative Standards 3-8
3.3.1.6 Distribution of Fatal Cancer risk 3-12
3.3.2 Control Technologies 3-12

3.4 Analysis of Benefits and Costs 3-15
3.4.1 Benefits 3-16
3.4.2 Costs 3-16

3.5 Economic Impact Analysis 3-25

REFERENCES 3-28

4. LICENSED MILL TAILINGS 4-1

4.1 Introduction and Summary 4-1
4.1.1 Rulemaking History and Current Regulations 4-2

4.2 Industry Profile 4-3
4.2.1 Demand 4-3
4.2.1.1 Uranium Uses 4-5
4.2.2 Sources of Supply 4-10
4.2.3 Industry Structure and Performance 4-21
4.2.4 Economic and Financial Characteristics 4-24
4.2.4.1 Employment Analysis 4-24
4.2.4.2 Community Impact Analysis 4-26
4.2.4.3 Financial Analysis 4-27
4.2.5 Industry Forecast and Outlook 4-31
4.2.5.1 Projections of Domestic Production 4-33
4.2.5.2 Near-Term Projections 4-34
4.2.6 Evaluation of Forecasts and Uranium Market Demand 4-36
4.2.6.1 Domestic Uranium Resources 4-36
4.2.6.2 Total Electricity Generation 4-42
4.2.6.3 Employment Projections 4-44

4.3 Current Emissions, Risks, and Control Methods 4-47

4.3.1 Current Emissions and Estimated Risk Levels 4-49
4.3.1.1 Methodology for the Assessment of Risks from Operating and Standby Mills 4-49
4.3.1.2 Methodology for the Assessment of Post-disposal Risks 4-53
4.3.1.3 Methodology for the Assessment of Risks from New Impoundments. 4-56

TABLE OF CONTENTS

Page

4.3.1.4 Exposures and Risks from Operating and Standby Mills 4-56
4.3.1.5 Post-disposal Exposures and Risks 4-59

4.3.2 Technologies for Long-term Post-disposal Emission Control 4-63

4.4 Analysis of Benefits and Costs 4-65

4.4.1 Benefits and Costs of Reducing Allowable Limits From 20 pCi/m^2/sec . 4-66
4.4.1.1 Benefits of Reducing the Allowable Limits 4-66
4.4.1.2 Costs of Reducing the Allowable Limits 4-67
4.4.2 Benefit And Costs of Reducing Allowable Emissions During Operations 4-73
4.4.2.1 Methods of Reducing Allowable Limits to 20 pCi/m^2/sec 4-73
4.4.2.2 Benefits of Reducing Allowable Limits to 20 pCi/m^2/sec 4-75
4.4.2.3 Costs of Reducing Allowable Limits to 20 pCi/m2/sec 4-75
4.4.3 Analysis of Benefits and Costs of Promulgating Future Work Practice Standards 4-77
4.4.3.1 Work Practices for New Tailings Impoundments 4-80
4.4.3.2 Comparison of Control Technologies for New Tailings Impoundments 4-81
4.4.3.3 Benefits of Promulgating Future Work Practice Standards 4-82
4.4.3.4 Costs of Promulgating Future Work Practice Standards 4-89

4.5 Economic Impacts 4-95
4.5.1 Increased Production Cost 4-95
4.5.2 Regulatory Flexibility Analysis 4-98

REFERENCES 4-101

5. HIGH-LEVEL WASTE DISPOSAL 5-1

5.1 Introduction and Summary 5-1

5.2 Industry Profile 5-1
5.2.1 Introduction 5-1
5.2.2 Facilities for the Ultimate Disposal of High-Level Waste 5-2
5.2.2.1 The Waste Isolation Pilot Plant (WIPP) 5-2
5.2.2.2 Yucca Mountain Geologic Repository 5-2
5.2.3 Demand for High-Level Waste Storage 5-2
5.2.4 Supply of High-Level Waste Storage 5-3

5.3 Current Emissions, Risk Levels and Feasible Control Methods 5-3
5.3.1 Introduction 5-3
5.3.2 Current Emissions and Estimated Risk 5-3
5.3.3 Control Technologies 5-4

5.4 Analysis of Benefits and Costs 5-4
5.4.1 Introduction 5-4
5.4.2 Least-Cost Control Technologies 5-4

TABLE OF CONTENTS

Page

5.4.3 Health and Other Benefits 5-5

5.5 Industry Cost and Economic Impact Analysis 5-5

REFERENCES 5-6

6. DEPARTMENT OF ENERGY FACILITIES 6-1

6.1 Introduction and Summary 6-1
6.2 Industry Profile 6-1
6.3 Current Risk Levels, and Feasible Control Methods 6-3
    6.3.1 Introduction 6-3
    6.3.2 Facility Descriptions 6-3
    6.3.3 Control Technologies 6-6

6.4 Analysis of Benefits and Costs 6-7
    6.4.1 Introduction 6-7
    6.4.2 Cost of Control Technologies 6-7
    6.4.3 Health and Other Benefits 6-10

6.5 Industry Cost and Economic Impacts 6-11

REFERENCES 6-12

7. DEPARTMENT OF ENERGY RADON SITES 7-1

7.1 Introduction and Summary 7-1

7.2 Industry Profile 7-1
    7.2.1 Feed Materials Production Center (FMPC) 7-2
    7.2.2 Niagara Falls Storage Site (NFSS) 7-2
    7.2.3 Weldon Spring Site (WSS) 7-2
    7.2.4 Middlesex Sampling Plant (MSP) 7-3
    7.2.5 Monticello Uranium Mill Tailings (MUMT) Pile 7-4

7.3 Current Emission, Risk Levels, and Feasible Control Methods 7-4
    7.3.1 Introduction 7-4
    7.3.2 Current Emissions and Estimated Risk Levels 7-4
        7.3.2.1 FMPC 7-4
        7.3.2.2 NFSS 7-7
        7.3.2.3 WSS 7-7
        7.3.2.4 MSP 7-7
        7.3.2.5 MUMT 7-8
    7.3.3 Control Technologies 7-8

7.4 Analysis of Benefits and Costs 7-9
    7.4.1 Costs and Benefits of Meeting Various Radon Flux Rates 7-9
        7.4.1.1 FMPC 7-10

TABLE OF CONTENTS

Page

7.4.1.2 NFSS 7-10
7.4.1.3 WSS 7-10
7.4.1.4 MSP 7-14
7.4.1.5 MUMT 7-14
7.4.2 Sensitivity Analysis 7-14

7.5 Industry Cost and Economic Impact Analysis 7-15

REFERENCES 7-19

8. ELEMENTAL PHOSPHORUS PLANTS 8-1

8.1 Introduction and Summary 8-1

8.2 Industry Profile 8-3

8.2.1 Demand 8-3
8.2.2 Supply 8-7
8.2.2.1 Monsanto Company 8-10
8.2.2.2 FMC Corporation 8-13
8.2.2.3 Rhône-Poulenc (Stauffer) 8-13
8.2.2.4 Occidental Petroleum Corporation 8-18
8.2.3 Competitive Products and Processes 8-18
8.2.4 Economic and Financial Characteristics 8-20
8.2.4.1 Prices 8-21
8.2.4.2 Employment 8-21
8.2.5 Outlook 8-21

8.3 Current Emissions, Risk Levels, and Feasible Control Methods 8-24

8.3.1 Current Emissions and Estimated Risk Levels 8-25
8.3.1.1 Process Description 8-25
8.3.1.2 Existing Effluent Controls 8-26
8.3.1.3 Emissions 8-26
8.3.2 Control Technologies for Elemental Phosphorus Plants 8-31
8.3.3 Cost of Control Technologies 8-32
8.3.3.1 Venturi Scrubber Cost Assumptions 8-33
8.3.3.2 Wet ESP Cost Assumptions 8-34
8.3.3.3 SD/FF Cost Assumptions 8-34
8.3.3.4 HEPA Filter Cost Assumptions 8-35
8.3.4 Emissions Control Alternatives 8-36
8.3.5 Performance of Control Alternatives 8-38

8.4 Analysis of Benefits and Costs 8-39

8.4.1 Benefits of Po-210 Emissions Control 8-39
8.4.2 Costs of Po-210 Emissions Control 8-50
8.4.3 Estimates of Benefits and Costs 8-56
8.4.4 Alternatives for Ample Margin of Safety for Elemental Phosphorus ... 8-64

TABLE OF CONTENTS

Page

8.5 Economic Impact Analysis 8-70

8.5.1 Production Costs 8-72
8.5.1.1 Components of Cost 8-72
8.5.1.1.1 Phosphate Rock 8-74
8.5.1.1.2 Coke 8-74
8.5.1.1.3 Electricity 8-74
8.5.1.1.4 Labor 8-76
8.5.1.2 Total Costs Per Plant 8-76
8.5.2 Measuring Economic Impacts 8-76
8.5.3 Regulatory Flexibility Analysis 8-83

REFERENCES 8-86

9. PHOSPHOGYPSUM STACKS 9-1

9.1 Introduction and Summary 9-1

9.2 Industry Profile 9-1

9.2.1 Characteristics of Phosphoric Acid Production 9-3
9.2.1.1 Determinants of Phosphoric Acid Supply 9-3
9.2.1.2 Products 9-22
9.2.1.3 U.S. Phosphate Producers 9-22
9.2.1.4 Employment 9-33
9.2.2 Characteristics of Phosphoric Acid Demand 9-35
9.2.2.1 Determinants of Domestic Demand 9-35
9.2.2.2 Determinants of Foreign Demand 9-39
9.2.2.3 World Demand for U.S. Phosphate Exports 9-41
9.2.2.4 Demand Forecasts 9-48
9.2.3 Other Issues 9-52
9.2.3.1 Substitutes 9-52
9.2.3.2 Alternative Uses for Phosphogypsum 9-53

9.3 Current Emissions, Risk Levels and Feasible Control Methods 9-59

9.3.1 Introduction 9-59
9.3.2 Physical Attributes of Phosphogypsum Stacks 9-60
9.3.2.1 Design and Construction 9-60
9.3.2.2 Radon Emissions from Uncontrolled Stacks 9-60
9.3.2.3 Risks Due to Controlled Stacks 9-62
9.3.3 Feasible Control Methods 9-62
9.3.3.1 Description of Controls 9-62
9.3.3.2 Costs of Controls 9-67
9.3.3.3 Emission Reductions Due to Controls 9-68
9.3.3.4 Reduction of Risk Due to Controls 9-69

TABLE OF CONTENTS

Page

9.4 Analysis of Benefits and Costs 9-69

9.4.1 Introduction 9-69
9.4.2 Least-Cost Control Technologies for Affected Plants 9-69
9.4.3 Health Benefits of Controlling Radon Emissions 9-72
9.4.4 Health Benefits and Cost Estimates 9-72
9.4.5 Sensitivity Analysis 9-78

9.5 Industry Cost and Economic Impact Analysis 9-78

9.5.1 Introduction 9-78
9.5.2 Production Costs and Market Prices 9-79
9.5.3 Measuring Economic Impacts 9-85
9.5.3.1 Background 9-85
9.5.3.2 Changes in Quantity of P_20_5 Produced Due to Control Requirements 9-86
9.5.3.3 Methodology for Estimating Economic Impacts 9-87
9.5.3.4 Other Impacts of Radon Control Requirements on the U.S. Economy 9-93

9.6 Regulatory Flexibility Analysis 9-95

9.6.1 Introduction 9-95
9.6.2 Small Business 9-95
9.6.3 Small Government Entities 9-95
9.A Appendix A 9-A1
9.B Appendix B 9-B1

REFERENCES 9-96

10. COAL-FIRED BOILERS 10-1

10.1 Introduction and Summary 10-1

10.2 Industry Profile 10-1
10.2.1 Demand 10-2
10.2.2 Supply 10-2
10.2.3 Industry Structure and Profile 10-2

10.3 Current Emissions, Risk Levels, and Feasible Control Methods 10-6
10.3.1 Introduction 10-6
10.3.2 Current Emissions and Estimated Risk 10-6
10.3.3 Control Technologies 10-6

10.4 Analysis of Benefits and Costs 10-8
10.4.1 Introduction 10-8
10.4.2 Least-cost Control Technologies 10-11
10.4.3 Health and Other Benefits 10-11
10.4.4 Estimates of Benefits and Costs 10-11

TABLE OF CONTENTS

Page

REFERENCES 10-17

11. NRC-LICENSED AND NON-DOE FEDERAL FACILITIES 11-1

11.1 Introduction and Summary 11-1

11.2 Industry Profile 11-2

11.3 Current Emissions, Risk Levels, and Feasible Control Methods 11-3
  11.3.1 Introduction 11-3
  11.3.2 Current Emissions and Estimated Risk Levels 11-3
  11.3.3 Control Technologies 11-6

11.4 Analysis of Benefits and Costs 11-7
11.5 Industry Cost and Economic Impact 11-7

REFERENCES 11-10

12. SURFACE URANIUM MINES 12-1

12.1 Introduction and Summary 12-1

12.2 Industry Profile 12-1
  12.2.1 Introduction 12-1
  12.2.2 Demand for Uranium 12-1
  12.2.3 Supply of Uranium 12-2

12.3 Current Emissions, Risk Levels, and Feasible Control Methods 12-7

12.4 Analysis of Benefits 12-7

12.5 Industry Cost and Economic Impact Analysis 12-7

REFERENCES 12-8

LIST OF TABLES

Table

1-1 Uranium Mills Licensed by the Nuclear Regulatory Commission 1-3

1-2 Uranium Mill Capacity (Tons of Ore per Day) 1-4

1-3 Light Water Commercial Fuel Fabrication Facilities Licensed by the NRC as of June, 1987 1-6

1-4 Fatal Cancer Risks from Atmospheric Radioactive Emissions from Uranium Fuel Cycle Facilities 1-8

1-5 Atmospheric Radioactive Emissions Assumed for References Dry and Wet Process Uranium Conversion Facilities 1-10

1-6 Fatal Cancer Risk Due to Atmospheric Radioactive Emissions - Uranium Conversions Facilities 1-11

1-7 Fatal Cancer Risks due to Atmospheric Radioactive Emissions - Uranium Conversion Facilities 1-12

2-1 Currently Operating Underground Uranium Mines in the United States 2-9

2-2 Current Risk Levels due to Radon-222 2-10

2-3 Alternative 1: Measures taken and their effects on Maximum Exposed Individuals 2-12

2-4 Alternative 2: Measures taken and their effects on Maximum Exposed Individuals 2-14

2-5 Alternative 3: Measures taken and their effects on Maximum Exposed Individuals 2-15

2-6 Matrix of MIRS as Stack Height and Emissions at Pigeon Mines Vary 2-16

2-7 Pigeon Mine, Summary of Risk Reductions and Costs 2-18

2-8 Matrix of Costs of Various Combinations of Stack Height and Shut-down Times for Pigeon Mine 2-19

2-9 Health Benefits due to Alternative One 2-22

2-10 Health Benefits due to Alternative Two 2-23

2-11 Health Benefits due to Alternative Three 2-24

LIST OF TABLES

		Page
2-12	Costs of Alternative One	2-25
2-13	Costs of Alternative Two	2-26
2-13	Costs of Alternative Three	2-26
2-10	Number of Miners and Shifts per Day by Mine	2-29
2-11	Number of Miners and Mining Operations by County	2-29
3-1	Status and Planned Remedial Action at Inactive Uranium Mill Sites	3-4
3-2	Summary of Radon-222 Emissions from Inactive Uranium Mill Tailings Disposal Sites	3-7
3-3	Estimated Number of Persons Living Within 5 km of the Centroid of Tailings Disposal Sites for Inactive Mills	3-9
3-4	Estimated Exposures and Risks to Nearby Populations Assuming Alternative Flux Rates	3-10
3-5	Estimated Fatal Cancers Per Year in the Regional (0-80km) Populations Assuming Alternative Flux Rates	3-11
3-6	Estimated Distribution of Fatal Cancer Risks to the Regional (0-80km) Populations Assuming Alternative Flux Rates	3-13
3-7	Total and Annualized Risk and Reduction of Risk (Committed Cancers) of Lowering the Allowable Limit to 6 pCi/m^2/sec and to 2 pCi/m^2/sec	3-17
3-8	Costs of Achieving the Doe Approved Design Flux	3-19
3-9	Costs of Achieving the 6 pCi/m^2/sec Option	3-20
3-10	Costs of Achieving the 2 pCi/m^2/sec Option	3-21
3-11	Incremental Present Value Costs of Lowering the Allowable Limit to 6 pCi/m^2/sec and to 2 pCi/m^2/sec	3-22
3-12	Incremental Annualized Cost of Lowering the Allowable Limit to 6 pCi/m^2/sec and to 2 pCi/m^2/sec	3-23
4-1	Status of U.S. Nuclear Power Plants as of December 31, 1986.	4-6
4-2	Deliveries of Uranium to DOE Enrichment Plants by Domestic Utilities	4-7

LIST OF TABLES

Page

4-3 Exports of Uranium (Thousand Short Tons of U_3O_8) 4-8

4-4 Average Contract Price and Market Price Settlements for Actual Deliveries 1982-1986 4-11

4-5 Historical Nuexco Exchange Values (Nominal Dollars Per Pound of U_3O_8) 4-12

4-6 Prices for Foreign-Origin Uranium 4-13

4-7 Total Uranium Concentrate Production, 1947-1986 4-15

4-8 Production of Uranium Concentrate by Conventional Mills and Other Sources, 1974-1986 (Short Tons U_3O_8) 4-16

4-9 Uranium Mill Capacity (Tons of Ore Per Day) 4-18

4-10 Import of Uranium Concentrate for Commercial Uses, 1974-1986 (Short Tons U_3O_8) 4-19

4-11 U.S. Commercially-Owned Uranium Inventories as of December 31, 1984, 1985, and 1986 (Short Tons U_3O_8 Equivalent) 4-20

4-12 Capital Expenditures, Employment, and Active Mills: Conventional Uranium Milling Industry 4-22

4-13 Operating Status and Capacity of Licensed Conventional Uranium Mills as of June, 1989 4-23

4-14 Employment in the U.S. Uranium Milling Industry by State 4-25

4-15 Financial Statistics of Domestic Uranium Industry, 1982-1986 4-28

4-16 Homestake Mining Company Uranium Operations, 1982-1986 4-30

4-17 Rio Algom Uranium Operations, 1981-1986 4-32

4-18 Annual and Projected Domestic Production of Yellowcake 1980-2000 4-35

4-19 Projected Nuclear Power Capacity (Reference Case) 4-38

4-20 Domestic Uranium Resources Endowment (Thousands of Short Tons) 4-40

4-21 Projections of Consumption of Electricity from Domestic 9-235 in 2000 Under the Reference Case Scenario 4-43

4-22 Average Annual Percentage Change in Electricity Consumption, 1987-2000 4-45

LIST OF TABLES

Page

4-23 Average Annual Percentage Change in Per Capita Electricity Consumption, 1987-2000 4-46

4-24 Employment Projects 1987-2000 (Person Years) 4-48

4-25 Summary of Operable Tailings Impoundment Areas Radium-226 Content at Operating and Standby Mills 4-51

4-26 Summary of Radon Source Terms Calculated for Operable Mill Tailings Impoundments 4-52

4-27 Estimated Number of Persons Living Within 5 km of the Centroid of Tailings Impoundments of Licensed Mills 4-54

4-28 Summary of Uranium Mill Tailings Impoundment Areas, Flux Rates, and Post-UMTRCA Radon-222 Release Rates 4-55

4-29 Estimated Exposures and Risks to Individuals Living Near Operable Tailings Impoundments with No Controls. 4-57

4-30 Estimated Fatal Cancers per Year in the Regional (0-80km) Populations Around Operable Tailings Impoundments 4-58

4-31 Estimated Distribution of the Fatal Cancer Risk to the Regional Populations from Operable Tailings Piles 4-58

4-32 Estimated Exposures and Risks to Nearby Populations Assuming Alternative Flux Rates 4-60

4-33 Estimated Fatal Cancers per Year in the Regional Populations Assuming Alternative Radon Flux Rates 4-61

4-34 Estimated Distribution of Fatal Cancer Risk to the Regional Populations Assuming Alternative Flux Rates 4-62

4-35 Total and Annualized Risk and Reduction of Risk of Lowering the Allowable flux Limit to 6 and 2 pCi/m^2/sec 4-68

4-36 Costs of Achieving the 20 pCi/m2/sec Option (1988 Dollars, Millions) 4-69

4-37 Costs of Achieving the 6 pCi/m2/sec Option (1988 Dollars, Millions) 4-70

4-38 Costs of Achieving the 2 pCi/m2/sec Option (1988 Dollars, Million) 4-71

4-39 Incremental Present Value Cost of Lowering the Allowable Limit to 6 pCi/m2/sec and 2 pCi/m2/sec . (1988 Dollars, 1989 through 2088) 4-72

LIST OF TABLES

Page

4-40 Incremental Annualized Cost of Lowering the Allowable Limit to 6 pCi/m2/sec and 2 pCi/m2/sec (1988 Dollars, 1989 through 2088) 4-74

4-41 Risks and Reduction of Risks for Continued Operations at 20 pCi/m^2/sec 4-76

4-42A Earth and Water Cover Required to Achieve Emissions of 20 pCi/m^2/sec 4-78

4-42B Cost of Earth Cover and Water Required to Achieve Emissions of 20 pCi/m^2/Sec 4-79

4-43 Estimated Total Cost For New Tailings Control Technology (Millions of 1985 Dollars) 4-84

4-44 Radon-222 Emissions and Emissions Reduction Resulting From Alternative Work Practices (kCi) 4-85

4-45 Radon-222 Risks and Reductions of Risks Resulting From Alternative Work Practices (Committed Cancers) 4-88

4-46 Costs For a Single Cell Partially Below Grade New Model Tailings Impoundment 4-90

4-47 Costs For a Phased Design Partially Below Grade New Model Tailings Impoundment 4-91

4-48 Costs For a Continuous Design Partially Below Grade New Model Tailings Impoundment 4-92

4-49 Summary of Net Present Values of Alternative Work Practices (Millions of 1988 Dollars) 4-93

4-50 Summary of Annualized Costs of Alternative Work Practices (Millions of 1988 Dollars) 4-94

4-51 Comparison of the Present Value of the Estimated Cost of Impacts with Selected Financial Statistics of the Domestic Uranium Industry: 1982-1986 4-97

4-52 Impacts on the Electrical Power Industry 4-99

4-53 Electrical Generation by NKRC Region, 1987 4-100

4A-1 Calculation of Cost of Water Required to Reduce Allowable Emissions to 20 pCi/m^2/sec 4-105

5-1 Emissions and Risks from Normal Operation at

LIST OF TABLES

Page

HLW Disposal Facilities 5-4

6-1 Department of Energy Facilities 6-2

6-2 Summary of Estimated Risks Around DOE Facilities 6-4

6-3 DOE Facilities Fatal Cancer Risks With and Without Supplementary Alternative 4 Controls 6-8

6-4 Controls, Risk Reduction, and Costs Associated with Meeting Alternative 4, by Facility 6-9

7-1 Exposures and Risks to Nearby Individuals From DOE Radon Sites 7-5

7-2 Estimated Fatal Cancers Per Year; in the Regional (0-80km) Populations Around DOE Radon Sites 7-6

7-3 Costs and Reduced Risks Resulting from Covering the Sources to Lower Radon Flux Rates to 20 pCi/m2/sec 7-11

7-4 Costs and Reduced Risks Resulting from Covering the Sources to Lower Radon Flux Rates to pCi/m2/sec 7-12

7-5 Costs and Reduced Risks Resulting from Covering the Sources to Lower Radon Flux Rates to 2 pCi/m2/sec 7-13

7-6 Reduction in Emissions and Cancer Rates Attributable to Controls: U.S. Totals 7-15

7-7 Incremental Costs and Risk Reductions for Various Flux Standards 7-16

7-8 Net Present Value of Cost of Supplemental Contracts to Meet a Flux of 20 pCi/m2/sec at DOE Radon Facilities: U.S. Total 7-18

8-1 Production and Shipment of Elemental Phosphorus -- 1964-1987 (tons) 8-4

8-2 Uses for Phosphorus Chemicals 8-5

8-3 Elemental Phosphorus Producers and Estimated Capacity 8-8

8-4 U.S. Capacities for Phosphorus and Phosphorus Chemicals - 1985 8-9

8-5 Elemental Phosphorus Production Capacity 8-11

8-6 Revenues from Elemental Phosphorus Production and Total Corporate Revenues 8-12

8-7 Elemental Phosphorus Market Share: Monsanto 8-14

LIST OF TABLES

Page

8-8 Monsanto's Position in Phosphorus Markets -- 1984 8-14

8-9 Elemental Phosphorus Market Share: FMC 8-15

8-10 FMC's Position in Phosphorus Markets - 1984 8-15

8-11 Elemental Phosphorus Market Share: Stauffer 8-17

8-12 Stauffer's Position in Phosphorus Markets 8-17

8-13 Elemental Phosphorus Market Share: Occidental 8-19

8-14 Occidental's Position in Phosphorus Markets - 1984 8-19

8-15 Average Price Range -- Phosphorus -- White 8-22

8-16 1987 Employment by State for the Elemental Phosphorus Industry 8-23

8-17 Radionuclide Emissions from Calciners at Elemental Phosphorus Plants 8-28

8-18 Estimated Annual Radionuclide Emissions from Elemental Phosphorus Plants . . 8-28

8-19 Populations and Distances to the Maximum Exposed Individuals Around Elemental Phosphorus Plants 8-29

8-20 Fatal Cancer Risks from Radionuclide Emissions from Elemental Phosphorus Plants 8-30

8-21 Distribution of Lifetime Fatal Cancer Risk in the Regional (0-80 km) Population Around Operating Elemental Phosphorus Plants 8-30

8-22 Distribution of Lifetime Fatal Cancer Risk in the Regional (0-80 km) Population Around Idle Elemental Phosphorus Plants 8-30

8-23 Estimated Po-210 and Pb-210 Emissions at the Scrubber/ESP Inlet 8-39

8-24 Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal: Industry Totals 8-40

8-25 Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at FMC's Pocatello, Idaho, Plant 8-41

8-26 Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at Monsanto's Soda Springs, Idaho, Plant 8-42

8-27 Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at Stauffer's Mount Pleasant, Tennessee, Plant 8-43

8-28 Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at Stauffer's Silver Bow, Montana, Plant 8-44

LIST OF TABLES

Page

8-29 Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at Occidental's Columbia, Tennessee, Plant 8-45

8-30 Estimated Po-210 Emission Levels Achieved by Control Alternatives 8-47

8-31 Fatal Cancer Risks from Radionuclide Emissions from Elemental Phosphorus Plants and Risk Reductions from Alternate Control Technologies 8-48

8-31a Reduction in Fatal Cancer Risks to Nearby Individuals and to Regional Populations for Each Alternate Control Technology 8-49

8-32 Control Technology Costs and Estimated Po-210 Emission Rates at FMC's Pocatello, Idaho, Plant 8-51

8-33 Control Technology Costs and Estimated Po-210 Emission Rates at Monsanto's Soda Springs, Idaho, Plant 8-52

8-34 Control Technology Costs and Estimated Po-210 Emission Rates at Stauffer's Mount Pleasant, Tennessee, Plant 8-53

8-35 Control Technology Costs and Estimated Po-210 Emission Rates at Stauffer's Silver Bow, Montana, Plant 8-54

8-36 Control Technology Costs and Estimated Po-210 Emission Rates at Occidental's Columbia, Tennessee, Plant 8-55

8-37 Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant -- FMC - Idaho 8-57

8-38 Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant -- Monsanto - Idaho 8-58

8-39 Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant -- Occidental - Tennessee 8-59

8-40 Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant -- Stauffer - Montana 8-60

8-41 Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant -- Stauffer - Tennessee 8-61

8-42 Total Annualized Costs of Alternative Emissions Standards: Sum of All Operating Plants 8-62

8-43 Total Incidence with Alternative Emissions Standards: Sum of All Operating Plants 8-63

8-44 Alternatives for Ample Margin of Safety for Elemental Phosphorus Plants,

LIST OF TABLES

Page

According to Various Emissions Levels 8-65

8-44a Alternatives for Ample Margin of Safety for Elemental Phosphorus Plants, Using Different Control Technologies 8-68

8-45 Cost of Elemental Phosphorus 8-73

8-46 Costs of Phosphate Rock Used in Phosphorus Production 8-75

8-47 Costs of Electricity Used in Phosphorus Productions 8-77

8-48 Labor Costs 8-78

8-49 Summary of Cost Estimates, by Plant 8-79

8-50 Revenues from Elemental Phosphorus Production and Total Corporate Revenues 8-82

8-51 Impact on Capital Expenditures 8-84

9-1 Production of Phosphoric Acid, Wet Process Phosphoric Acid, and Phosphate Fertilizer Metric Tons 9-4

9-2 Price of Phosphoric Acid, Sulfur, Phosphate Rock and Diammonium Phosphate 9-8

9-3 Phosphate Fertilizer Production Costs 9-10

9-4 Phosphate Rock Statistics on World Supply Rock Mining Capacity 9-13

9-5 Phosphate Rock Statistics on World Supply Demonstrated Rock Reserves 9-14

9-6 U.S. Sulphur Recover Trends 1980-1985 9-21

9-7 Financial Condition of Phosphate Industry 9-25

9-8 Producers of Phosphate Rock, Wet Process Phosphoric, and Phosphate Fertilizers (Thousand Metric Tons Per Year) 9-26

9-9 Capacities of Major Phosphoric Acid Producers, Estimates for 1988/89 (Metric Tons Per Year) 9-27

9-10 Operating Rates for U.S. Fertilizer Producers 9-28

9-11 Employment in the Phosphate Industry (Thousands) 9-34

9-12 U.S. Exports of Phosphate Fertilizers (Thousand Metric Tons, Thousand Dollars) 9-45

LIST OF TABLES

Page

9-13 Trade in Phosphate Products by Major Exporter, 1981-1984 Phosphate Fertilizer (Metric Tons, P_2O_5) 9-47

9-14 Summary of World Phosphate Fertilizer Demand Forecasts (Million Nutrient Metric Tons P_2O_5) 9-49

9-15 Forecasts of Fertilizer Demand by Region and Source, 1995-2000 9-51

9-16 Stack Parameters 9-61

9-17 Radon Flux Rates by Regional Group 9-63

9-18 Incremental Cancer Risks Associated With Exposure to Radon Emitted From Phosphogypsum Stacks with No Controls 9-64

9-19 Control Parameters for Representative Stacks 9-66

9-20 Reduction in Risk to the Most Exposed Individual 9-70

9-21 Reduction in Risk to Population Within 80km of Stack 9-71

9-22 Cost Effectiveness of Control in Terms of Emission Reductions 9-73

9-23 Cost of Controlling Radon in Dollars Per 1000/MT of Plant Capacity, Annualized Over A Five Year Period 9-80

9-24 World Market Share of U.S. P_2O_5 Producers Exports in Absence of Radon Control Measures in 1000 MT (Lower Phosphate Rock Cost) 9-89

9-25 World Market Share of U.S. P_2O_5 Producers Exports in Absence of Radon Control Measures in 1000 MT (Higher Phosphate Rock Cost) 9-90

10-1 Coal Ash Distribution by Boiler Type 10-4

10-2 Numbers and Capacities of Industrial Boilers 10-5

10-3 Typical Uranium and Thorium Concentrations in Coal 10-7

10-4 U-238 Emission Factors for Coal-Fired Utility Boilers 10-9

10-5 Th-232 Emission Factors for Coal-Fired Utility Boilers 10-10

10-6 Estimated Radiation Dose Rates from Large Coal-Fired Utility Boilers 10-12

10-7 Estimated Radiation Dose Rates from the Reference Coal-Fired Industrial Boiler 10-13

LIST OF TABLES

Page

10-8 Estimated Distribution of the Fatal Cancer Risk to the Regional (0-80km) Populations from All Coal-Fired Utility Boilers 10-14

10-9 Estimated Distribution of the Fatal Cancer Risk to the Regional (0-80km) Populations from All Coal-Fired Industrial Boilers 10-15

11-1 NRC Licensed and Non-DOE Facilities Fatal Cancers Per Year 11-4

11-2 Costs and Benefits for Controls on the Two Sources for Which Controls are Required 11-8

12-1 Number of Significant Production Surface Uranium Mines by State 12-4

12-2 Reasonably Assured Resources by Mining Method At the End of 1986 in the U.S. (million pounds of U_3O_8) 12-5

12-3 United States and Selected Foreign Uranium Resources as of End of 1986. 12-6

LIST OF FIGURES

Figure | Page

2-1 Costs of Controls by Stack Height 2-19

3-1 Cost of Lowering the Allowable Flux 3-24

4-1 Sources of Uranium Supply 4-37

4-2 U.S. Uranium Production 4-37

4-3 Model Impoundment Emissions (kCi/Year) 4-86

9-1 Price of P_2O_5 and Related Products 9-7

9-2 Uses for Phosphoric Acid, 1985-86 9-23

9-3 United States Fertilizer Consumption 9-38

9-4 U.S. P205 Exports (Lower Rock Costs) 9-92

9-5 U.S. P205 Exports (Higher Rock Costs) 9-92

12-1 Uranium Production U.S. Open-Pit Mines and Total Output 12-3

CHAPTER 1

URANIUM FUEL CYCLE

1. URANIUM FUEL CYCLE FACILITIES

1.1 Introduction and Summary

The uranium fuel cycle involves six types of major industrial facilities. These major facilities include:

- Uranium mills
- Uranium hexaflouride conversion facilities
- Uranium enrichment facilities
- Fuel fabricators
- Light-water power reactors
- Fuel reprocessing plants

Releases of radioactive materials from these sources are subject to the limits established by 40 CFR 190. A comprehensive evaluation of the potential public health impacts of the release of radioactive materials into the ambient air from the uranium fuel cycle was prepared by the EPA and a list can be found in Volume 2 of this Final *Environmental Impact Statement* [EPA89]. The uranium enrichment facilities are discussed in Chapter 6, "Department of Energy Facilities." Fuel reprocessing plants are not discussed since there are currently no operating fuel reprocessing plants in the United States. The remaining four types of facilities are discussed below.

This chapter will provide a brief industry profile, estimates of emissions and associated risk levels, discussion of feasible emission control methods, and an economic impact analysis. The risk to regional populations (persons living within 80 km of the source) from the four facility types covered in this chapter[1] are estimated to be equivalent to one fatal cancer every one hundred years. Risk to both regional and national populations are estimated to be equivalent to one fatal cancer every ten years [EPA89].

---

[1] Excluding radon emissions from uranium mill tailings.

1.2 Industry Profile

1.2.1 Introduction

The four major components of the uranium fuel cycle included in this chapter are uranium mills, uranium conversion facilities, fuel fabrication facilities, and nuclear power facilities. These facilities are licensed by the Nuclear Regulatory Commission (NRC) or the Agreement States. Each of these four facility types are briefly described below. More detailed descriptions for some may be found in complementary chapters for uranium mill tailing piles and uranium enrichment plants. A fifth major component, uranium enrichment facilities, are owned by the Federal government and operated by contractors under the direction of the Department of Energy (DOE). Enrichment facilities are considered in Chapter 6.

1.2.2 Uranium Mills

A detailed profile of the uranium mill industry is contained in Chapter 4: "Licensed Uranium Mill Tailings." Although there are 27 uranium mills within the U.S., only four were operating in 1988. Of the remainder, eight were on standby, fourteen were being decommissioned and one was never operated. The four operating mills have a total capacity of 9,600 tons of ore per day, reflecting a decline in capacity from 50,000 tons per day in 1981 when 21 plants were in operation, (Tables 1-1 and 1-2 present data on milling capacity and the recent capacity trends). These developments are due to a combination of 1) rising imports and 2) declining demand resulting from cancellation of nuclear power plant construction projects. Domestic production of yellowcake, the product of uranium milling, is expected to increase over ten percent by the year 2000, but short-run forecasts of domestic production call for a continuing decline [DOE87b]. The financial strength of the industry has weakened considerably since its peak demand years in late 1970's and early 1980's. The industry was unprofitable for three of the past five years.

1.2.3 Uranium Conversion Facilities

There are two commercially operating conversion facilities in the United States. These facilities purify uranium oxide or yellowcake to uranium hexafluoride (UF_6), the chemical form of the uranium entering the enrichment plant. The two conversion facilities are the Allied Chemical Corporation facility at Metropolis, Illinois and the Kerr-McGee Nuclear Corporation at Sequoyah, Oklahoma. The Allied plant is a dry process plant with a capacity of 12,600 metric tons per year and has been operational since 1968, while the Kerr-McGee plant is a wet process plant with a capacity

Table 1-1: Uranium Mills Licenses by the U.S. Nuclear Regulatory Commission as of December 1, 1988

Licensee	**Location**	**Rated Capacity (tons/day)**	**Status**	**Process**
American Nuclear	Gas Hills, WY	950	3	1,5
Anaconde	Bluewater, NM	6000	3	1,3
Atlas Minerals	Moab, UT	1400	3	2,3
Bear Creek Uranium	Converse Co., WY	2000	3	1,3
Bodum Resources	Marquez, NM	2000	4	1,3
Chevron Resources	Panna Maria, TX	2500	1	1,3
Conoco-Pioneer	Falls City, TX	3400	3	1,3
Cotter	Cannon City, CO	1200	2	1,3
Dawn Mining	Ford, WA	450	3	1,3
Exxon	Ray Point, TX	--	3	--
Exxon Minerals	Converse Co., WY	3200	3	1,3
Homestake Mining	Grants, NM	3400	1	4,6
BP American	Seboyeta, NM	1600	3	--
Minerals Exploration	Sweetwater Co., WY	3000	2	1,3
Pathfinder Mines	Gas Hills, WY	2500	2	1,3
Pathfinder Mines	Shirley Basin, WY	1700	1	1,3
Petrotomics	Shirley Basin, WY	1500	3	1,3
Plateau Resources	Shootaring, UT	750	2	1,3
Quivira	Ambrosia Lake, NM	--	2	--
Rio Alogm	La Sat, UT	750	2	4,6
TVA	Edgemont, SD	--	3	--
Umetco Minerals	Gas Hills, WY	1400	3	1,5
Umetco Minerals	Blanding, UT	2000	1	1,7
Umetco Minerals	Uravan, CO	1300	2	1,3
UNC Mining	Church Rock, NM	3000	3	1,3
Western Nuclear	Jeffrey City, WY	1700	3	1,3
Western Nuclear	Wellpinit, WA	2000	2	1,3

STATUS CODES:

1 = Facility Operating
2 = Facility Shutdown
3 = Facility Being Decommissioned
4 = Facility Built, Never Operated

PROCESS CODES:

1 = Acid Leach
2 = Alkaline Leach
3 = Solvent Extraction
4 = Carbonate Leach
5 = Eluex
6 = Caustic Precipitation
7 = Column ion exchange

SOURCE: [EPA89]

Table 1-2: Uranium Mill Capacity (Tons of Ore per Day)

Year	Total Capacity	Operating Capacity	Operating Capacity Utilization Rate	Total Capacity Utilization Rate
1981	54,050	49,800	83%	77%
1982	55,050	33,650	74%	45%
1983	51,650	29,250	58%	33%
1984	48,450	19,250	64%	25%
1985	47,250	6,550	78%	11%
1986	42,650	11,650	32%	9%

Source: (DOE 87)

of 9,100 tons per year that has operated since 1970 [AEC74, DOE88]. It is anticipated that the existing uranium conversion plants will be able to accommodate the future demand for uranium by nuclear power plants.

1.2.4 Fuel Fabrication Facilities

There are seven licensed uranium fuel fabrication facilities in the United States, but only five were actively operating as of January 1, 1988. Table 1-3 lists and describes the seven facilities. Light water reactor (LWR) fuels are fabricated from uranium which has been enriched in the U-235 isotope. The uranium hexafluoride, UF_6, is processed to increase the U-235 content from 0.7 percent up to two to four percent by weight. The enriched uranium hexafluoride product is shipped to the LWR fuel fabrication plant where it is converted into solid uranium dioxide pellets and inserted into zirconium tubes that are fabricated into fuel assemblies for use in nuclear power plants. Two of the five operating facilities use enriched uranium hexafluoride to produce fuel assemblies, while two use uranium dioxide. The fifth facility converts UF_6 to UO_2 and recovers uranium from scrap materials generated in the various processes at the plant. There are two processes used to convert UF_6 to UO_2 - a wet process, ammonium diuranate, and a dry process, direct conversion.

1.2.5 Light-water Power Reactors

There are 102 operable commercial nuclear power reactors in the United States. Of these, approximately two-thirds are pressurized water (PWR) and one-third are boiling water reactors (BWR) [NN88].

The future of the nuclear power industry in the United States depends on the demand for electricity, interest rates, prices of alternative fuels, environmental concerns, the regulatory climate, and public attitudes. The probable range of nuclear power capacity by the year 2000 is estimated to be from 100 to 110 plants.

1.3 Current Emissions, Risk Levels, and Feasible Controls Methods

1.3.1 Introduction

The emission rate for a facility will depend on the source and the control system currently in use. Risk levels depend on the emission levels, release points, demographic and meteorological factors and

Table 1-3: Light Water Commercial Fuel Fabrication Facilities Licensed by the Nuclear Regulatory Commission as of June, 1987.

Licensee	Facility Location	Operations	Process Used to Convert UF_6 to UO_2	Final Product	1980 Operating Capacity (tons/year)	Operating License as of June 1987
Advanced Nuclear Fuels	Richland, Washington	LEU a/ Conversion (UF_6 to UO_2), Fabrication & Scrap Recovery; Commercial LWR Fuel	Dry & Wet	Complete Fuel Assemblies	650	NO
Babcock & Wilcox - CNFP	Lynchburg, Virginia	LEU Fabrication; Commercial LWR Fuel	---	Use UO_2 Powder to Produce Fuel Assemblies	(250)	YES
Babcock & Wilcox	Apollo, Pennsylvania	Authorized Decontamination; Pending Nuclear Reactor Service Operations	Wet	UO_2 Powder	250	NO
Combustion Engineering	Windsor, Connecticut	LEU Fabrication; Commercial LWR Fuel	---	Use UO_2 Powder to Produce Fuel Assemblies	(150)	YES
Combustion Engineering	Hematite, Missouri	LEU Conversion (UF_6 to UO_2) & Scrap Recovery	Dry	UO_2 Powder	150	YES
General Electric	Wilmington, North Carolina	LEU Conversion (UF_6 to UO_2) & Fabrication; Commercial LWR Fuel	Dry & Wet	Complete Fuel Assemblies	1,500	YES
Westinghouse Electric	Columbia, South Carolina	LEU Conversion (UF_6 to UO_2); Fabrication & Scrap Recovery; Commercial LWR Fuel	Dry & Wet	Complete Fuel Assemblies	750	YES
TOTAL					3,300	

a/ Low enrichment uranium

Source: [EPA89]

the pathways for exposure or ingestion. Estimates of exposure and lifetime fatal cancer risks to nearby individuals and to those within an 80 kilometer radius serve as the basis for the risk assessments. The risks are summarized in Table 1-4 for both nearby and regional populations [EPA89].

1.3.2 Current Emissions and Estimated Risk Levels

1.3.2.1 Uranium Mills

Emissions of radionuclides from uranium mills include those created during ore storage and milling processes, and those emitted by the mill tailings. Radon emissions from mill tailings piles are discussed in Chapter 4 of this volume and are not considered in this chapter.

Emissions from ore storage result from the drying of the ore and its subsequent entrainment by wind or from transfer operations. The milling process includes the crushing and grinding of ore and the leaching of uranium from the ore through either acid or alkaline processing, depending upon the lime content of the ore. The precipitate that is formed is then dried in large ovens and packaged for transport. After the uranium product that can be extracted by leaching is separated from the ore, the remaining ore is pumped as slurry to a tailings impoundment area. A portion of the liquid is recovered and recycled, while the remainder is allowed to evaporate, producing a solid tailings pile composed of a sand fraction and a slime fraction. Active tailings piles contain both wet and dry areas. As sections dry out, the tailings can become a source of windblown dust. The dried slime component is particularly prone to becoming windborne due to its small particle size. The process steps that generate the significant emissions (other than radon from tailings piles) are crushing, drying, and packaging. Ninety percent of the U-234 and U-238 are released from the dryer area, while the Th-230 and Ra-226 emissions result primarily from operations such as crushing.

Emissions for this source category are analyzed in detail in Chapter 4 of Volume 2 of the *Environmental Impact Statement*, including a description of the basis for the site-specific and model facilities used to assess the airborne releases of radionuclides from uranium mills. Also presented is information on the source term, meteorological, and demographic assumptions. Site-specific source term, meteorological, and demographic data for each of the four operating mills and for six of the seven mills on standby, were supplied as input to the assessment codes. A model mill was used for the assessment of doses and risks from the tailings piles of inactive mills. Outputs of the codes include estimates of: dose equivalents to the most exposed individuals (mrem/y); lifetime fatal

Table 1-4 Fatal Cancer Risks from Atmospheric Radioactive Emission from Uranium Fuel Cycle Facilities (Excluding Radon from Tailing Piles)

Facility	**Highest Individual Lifetime Fatal Cancer Risk**	**Regional (0-80 km) Population Deaths/y**
Uranium Mills		
Ambrosia Lake	2E-7	3E-5
Homestake	2E-4	2E-3
La Sal	2E-6	3E-5
Lucky Mc	1E-7	7E-6
Panna Maria	3E-6	5E-5
Sherwood	1E-6	8E-5
Shirley Basin	6E-7	9E-5
Shootaring	2E-7	7E-7
Sweetwater	7E-7	2E-5
White Mesa	6E-7	2E-5
Model Inactive Tailings	2E-4	1E-4

		Total 2E-3
Uranium Conversion		
Dry	3E-5	8E-4
Wet	4E-5	6E-4
Fuel Fabrication	4E-6	8E-5
Nuclear Power Reactors		
Pressurized Water Reactors	3E-6	7E-4
Boiling Water Reactors	5E-6	1E-3

cancer risk to the most exposed individuals; dose equivalents to the regional (0-80 km) population (person-rem/y); and the number of cancer deaths in the regional population per year of operation (deaths/year).

The fatal cancer risks are summarized in Table 1-4 for both nearby and regional populations affected by either operating or closed mills. The total deaths per year in the 80 km regional population for uranium mill segment of the source category is estimated to be 2E-3.

1.3.2.2 Uranium Fuel Conversion Facilities

Two processes are used to convert uranium oxide to uranium hexaflouride. The dry hydrofluor process generates higher uranium emissions than the solvent extraction process since large amounts of dust are produced in the sampling, pre-treatment, and reaction stages. The solvent extraction process releases uranium as both soluble and insoluble aerosols which are vented to the environment. The atmospheric emissions used in the risk assessments for the reference dry and wet conversion facilities are shown in Table 1-5. The plant parameters utilized are specific to each plant [NRC 84, NRC85b]. Table 1-4 shows fatal cancer risks due to atmospheric radioactive emissions. The risk to nearby individuals of fatal cancer is estimated at 3E-5 and 4E-5 for the dry and wet processes, respectively. The lifetime risk to the regional population is 8E-4 and 6E-4 fatal cancers per year for the dry and wet processes, respectively (see Table 1-6). The total risk for all uranium conversion facilities is estimated to be 1E-3 fatal cancers per year of operation in the regional populations, with a total of about 900,000 persons.

1.3.2.3 Uranium Fuel Fabrication Facilities

A model fuel fabrication facility was developed to estimate the risks associated with this class of facilities. The Westinghouse plant at Columbia, South Carolina was used as the basis for the model facility for most emissions.

Table 1-7 shows the expected emissions from the model plant. The climatological and demographic data utilized are representative of the area proximate to the Westinghouse Facility at Columbia, South Carolina which was the basis for the model plant. The predominant exposure pathway is via inhalation, primarily of U-234. On a regional basis the risk of fatal cancers is estimated to be 8E-5 per year of operation. The total risk for an assumed industry of five operating fuel fabrication facilities is approximately 4E-4 fatal cancers per year.

Table 1-5 Atmospheric Radioactive Emissions Assumed for Reference Dry and Wet Process Uranium Conversion Facilities.

Facility	Process	Radionuclide	Emissions (Ci/year)	Solubility D	Class W	(%)(a) Y
Allied Corp. Metropolis, IL	Dry	U-Natural(b)	0.10000	56	30	14
		Th-230(b)	0.00050	0	0	100
		Ra-226(b)	0.00001	100	0	
Sequoya Fuels Sequoya, OK	Wet	U-Natural(c)	0.050	65	5	30
		Th-230(c)	0.005	0	0	100
		Ra-226(c)	0.005	0	100	0

(a) Solubility classes D, W, and Y refer to the retention of inhaled radionuclides in the lungs; representative half-times for retention are less than 10 days for class D, 10-100 days for class W, and greater than 100 days for class W, and greater than 100 days for class Y.

(b) Particle size 3.4 um.

(c)

Particle size (um)	% (Average: 1980-1984)
4.2 to 10.2	9.3
2.1 to 4.2	9.7
1.3 to 2.1	5.5
0.69 to 1.3	6.5
0.39 to 0.69	13.5
0.00 to 0.39	55.3

SOURCE: [EPA 89]

Table 1-6 Fatal Cancer Risks due to Atmospheric Radioactive Emissions-Uranium Conversion Facilities

Process	**Nearby Individuals Lifetime Fatal Cancer Risk**	**Regional (0-80 Km) Population Deaths/Year**
Dry	3E-5	8E-4
Wet	4E-5	6E-4

Source: EPA 89

Table 1-7 Fatal Cancer Risks due to Atmospheric Radioactive Emissions-Uranium Conversion Facilities

Process	Nearby Individuals Lifetime Fatal Cancer Risk	Regional (0-80 Km) Population Deaths/Year
Dry	3E-5	8E-4
Wet	4E-5	6E-4

Source: EPA 89

1.3.2.4 Nuclear Power Reactors

Radionuclides are produced during the fission process and accumulate within the nuclear fuel. Reactors also experience periodic fuel failure, resulting in leakage of fission or activation products out of the fuel and into the coolant. The primary sources of gaseous emissions from boiling water reactors (BWR's) are from the off-gas treatment system and building ventilation system exhaust. Pressurized water reactors (PWR) discharge radioactive products through four systems, including those for BWRs plus the steam generator's blowdown exhaust and the exhaust of non-condensable gases at the main condenser.

The predominant pathway of exposure from BWRs is air immersion, resulting from the release of radioactive xenon and krypton. Air immersion and inhalation are the most important exposure pathways for the model PWRs, with the primary exposures coming from strontium-90 and xenon. Doses and risks were estimated in Volume 2 of the *Environmental Impact Statement*. The lifetime risk of fatal cancer for nearby individuals ranges from 3E-6 for the model PWR to 5E-6 for the model BWRs. The incremental risk to the regional population is 1E-3 fatal cancers per model BWR per year of operation and 7E-4 fatal cancers per model PWR per year of operation. Summing this risk across the population of power plants yields a total risk of 9E-2 cancers per year for the United States. These estimates assume non-overlapping populations for exposure to nuclear power reactors and may understate the risk to some individuals residing near multiple reactors.

1.3.3 Control Technologies

Currently available emission control techniques for the four components of the uranium fuel cycle covered by this chapter are discussed in the following sub-sections. Because all achieve emission control and risk levels that are considered adequate, no further work was done to identify more stringent emission control approaches.

1.3.3.1 Uranium Mills

Controls to reduce radioactive particulate emissions currently exist and can be applied to various stages of uranium milling. These include grinding and leaching of the ore to extract uranium oxide, drying and packaging the product, and storage of the mill tailings. These controls are briefly discussed in this section. Control of radon emissions from tailings piles is discussed in Chapter 4 of this volume.

Controls for emissions from the milling operations -- grinding, leaching, drying and packaging -- have been evaluated by the NRC [NRC80]. Milling dust is controlled by the placing of exhaust hoods at the crusher, screens and transfer points. The off-gases from the drying operation are passed through a dust separation system before discharge. Air exhaust hoods are placed in the packaging area and run through a dust collector prior to venting. The use of wet scrubbers is the primary method of removing dust from the exhaust gases. Rated collection efficiencies vary from approximately 94 to 99.9 percent depending upon the type of scrubber.

The cost for each additional tenth of a percent of improvement of efficiency increases as the efficiency level increases. For example, a medium-energy venturi scrubber, with 99.7 percent rated efficiency, costs $305,000 (in 1980 prices) over a fifteen year lifetime, while a high-energy venturi scrubber, with 99.9 percent rated efficiency, costs $430,000. The additional 0.2 percent of efficiency costs $125,000.

A variety of controls for windblown radioactive particulates from mill tailings piles have also been analyzed and are discussed in Volume 2, Chapter 4 of *Environmental Impact Statement*. These include: wetting of tailings, the use of tank trucks or sprinkling systems; leaching of tailings; solidification of tailings; application of stabilizers such as latex or polymers to tailings surfaces; and covering of tailings, either above or below ground. The application of latex stabilizers to the tailings piles is a cost-effective method for controlling dust from the piles. This method is currently in use and has proved effective for up to one year per application. Its cost is estimated at $1.03 million for an annual application to a 30 hectares pile.

The stationary sprinkling system is the second most cost effective alternative. When installed and operated by existing maintenance personnel, this alternative is more cost-effective than the application of latex stabilizers. The cost of a stationary sprinkling system to cover a total of 30 hectares is estimated to be $1.9 million. Some evidence at specific plants indicate that this cost can be reduced considerably [EPA89]. An added advantage of such a system is that evaporation of the tailings pond water, an operational goal of each milling operation, would be substantially increased. The value of this benefit has not been estimated.

1.3.3.2 Uranium Conversion Facilities

Well-proven particulate control technologies such as fabric filters and scrubbers can be added to the existing control systems at uranium hexafluoride conversion plants to reduce emissions. The selection of additional controls must take into account the presence of moisture and corrosive contaminants (particularly fluorine) in some of the exhaust lines.

A previous study has estimated the cost of providing additional fabric filters for both the wet and dry process plants [TEK81]. The estimated capital costs of the systems (1979 $) are approximately $2.1 million and $4.5 million for the wet and dry plant, respectively. The total annual costs (operating and maintenance) for the wet and dry process plants are approximately $0.6 million and $1.3 million, respectively [EPA89].

1.3.3.3 Uranium Fuel Fabrication Facilities

Current control techniques for fuel fabrication facilities depend upon the processes involved. The ammonium diuranate facility process gases are processed through wet scrubbers and high efficiency particle air (HEPA) filters with 90 and 95 percent efficiency, respectively. Ventilation off-gases are sent through roughing and HEPA filters prior to discharge. The direct conversion facility process gas is passed through sintered metal filters to remove solids and then to scrubbers for HF removal, dilution and final discharge.

1.3.3.4 Nuclear Power Reactors

Nuclear power reactors in use in the U.S. are of two types: boiling water reactors (BWRs) and pressurized water reactors (PWRs). While there are common approaches to control of radionuclide emissions released to the atmosphere from the two types of reactors, there are also differences in approach.

Both types of reactor use HEPA filters and charcoal filtration units to remove particulate and radioiodine emissions from building and ventilation exhausts. HEPA filters are designed and treated to ensure 99.97 percent efficiency for particulate emissions. Charcoal filters can be designed for various levels of efficiency, the most common of which has a decontamination factor of 100. Both also employ various strategies to delay the release of noble gases, allowing those with shorter lives to decay before being released. Both BWRs and PWRs also employ various indirect methods of reducing atmospheric emissions. These are applied to individual pumps, tanks and valves on a case-by-case basis.

There are also control strategies and methods that are applied to BWRs or PWRs uniquely, depending on their special features. Because there are so many possible configurations, and the cost of each element depends on factors specific to the application, there is no concise summary of costs for controlling radioactive emissions from nuclear power reactors.

1.4 Industry Cost and Economic Impact Analysis

Any radionuclide emission control costs imposed on the uranium fuel cycle facilities would be expected to weaken further the position of the domestic nuclear industry. Alternative sources of nuclear fuel supply from imports and the alternatives to nuclear electric power will become more attractive if uranium fuel production costs increase.

REFERENCES

AEC74 U. S. Atomic Energy Commission, Fuels and Materials Directorate of Licensing, *Environmental Survey of the Uranium Fuel Cycle*, April 1974.

DO88 Dolezal, W., personal communication with Dave Goldin, SC&A, Inc., September 1988.

DOE87 U.S. Department of Energy, *Domestic Uranium Mining and Milling Industry: 1986 Viability Assessment*, DOE/EIA-0477 (86), November 23, 1987.

EPA79 U.S. Environmental Protection Agency, *Radiological Impact Caused by Emissions of Radionuclides in Air in the United States*, preliminary report, EPA 520/7-79-006, August 1979.

EPA84a U. S. Environmental Protection Agency, *Final Rule for Radon-222 Emissions from Licensed Uranium Mill Tailings, Background Information Document for Final Rules*, volume II, EPA /520-1-84-022-2, October 1984.

EPA84b U. S. Environmental Protection Agency, *Radionuclides: Background Information Document for Final Rules*, volume I, EPA 520/1-84-022-2, October 1984.

EPA89 *Risk Assessments*, Vol. 2.

NN88 *Nuclear News*, February 1988.

NRC74 U. S. Nuclear Regulatory Commission, *Environmental Statement Related to Operation of Shirley Basin Mill*, December 1974.

NRC80 U. S. Nuclear Regulatory Commission, *Final Generic Environmental Impact Statement on Uranium Milling*, September 1980.

NRC82 U. S. Nuclear Regulatory Commission, *Technical Guidance for Siting Criteria Development, NUREG//CR-2239*, November 1982.

NRC84 U. S. Nuclear Regulatory Commission (NRC), *Environmental Impact Appraisal for the Renewal of Source License No. SUB-526*, NUREG-1071, May 1984.

NRC85a U. S. NRC, *Environmental Assessment for Renewal of Special Nuclear Material License No. SNM-1107*, NUREG-1118, May 1985.

NRC85b U. S. NRC, *op cit.*, August 1985.

CHAPTER 2

UNDERGROUND URANIUM MINES

2. UNDERGROUND URANIUM MINES

2.1 INTRODUCTION

Underground uranium mines are part of the domestic uranium industry that provides commercial nuclear power plants their fuel. Other industrial categories in this industry are surface uranium mines, uranium mills and other segments of the nuclear fuel cycle. All these activities are dependent to a degree on nuclear power plants to generate demand for their output.

As is detailed in Chapter 4 of this volume, "Licensed Uranium Mill Tailings," and summarized in this chapter, the demand for the products of domestic uranium production has been falling for some time. Most mines and mills have gone out of production and many are permanently closed. The remaining are analyzed here.

This chapter provides a brief profile of the uranium industry, describes the options for reducing radon emissions from underground mines, the health benefits attributable to each option, the costs attributable to each option and the impacts a regulation would have on the industry, the miners, their communities and the U.S. economy.

2.2 Industry Profile

The U.S. uranium mining industry is an integral part of a domestic uranium production industry that includes companies engaged in uranium exploration, mining, milling, and downstream activities leading to the production of fuel for nuclear power plants. The product of uranium mining is uranium ore.

2.2.1 Demand

Domestic producers of uranium ore send it to uranium mills. The mills have two markets for their production: the U.S. nuclear power industry and exports. The nuclear power industry is by far the more important of the two. Military uses, once the only source of demand for uranium, have been supplied solely by government stockpiles since 1970 [DOE 87a].

Demand for domestic uranium has declined since the late 1970s. In 1979, utilities delivered 15,450 tons of domestic uranium oxide to DOE for enrichment, 86 percent more than 1986 deliveries. Exports too have declined substantially. In 1979, exports amounted to 3,100 tons, almost four times as much as in 1986. A number of negative forces have combined to cause the current depressed state of the industry. Perhaps most importantly, the growth in electricity generated by nuclear plants and the expansion of nuclear power capacity has been much slower than had been forecast in the mid-1970s. This slower growth is due in part to numerous construction delays and cancellations. Second, imports have begun to play a major role in the U.S. uranium market. Import restrictions were gradually withdrawn between 1975 and 1985. The result has been a steady increase in uranium imports from nations possessing high grade (and thus low cost) uranium deposits. Expectations are that a growing portion of utility requirements will be supplied by foreign-origin uranium during the second half of this decade [JFA 85a].

Also contributing to the current downturn in the uranium industry are the large inventories being held by both producers and utilities. Utilities, anticipating a growing need for uranium, entered into long-term contracts to purchase large amounts of domestically-produced uranium. As actual needs fell short of expected needs due to nuclear power plant construction delays and cancellations, large inventories accumulated. These inventory supplies, currently estimated to cover four to five years of utility requirements, adversely affect suppliers in two ways. They may extend the downturn in uranium demand for a number of years by decreasing the need for utilities to enter into new contracts. Also, high interest rates increased inventory holding costs, leading some utilities to contribute to current excess supply by offering inventory stocks for sale on the spot market [JFA 85a]. More detail on uranium uses can be found in Chapter 4 of this volume.

2.2.2. Sources of Supply

The uranium used to fuel nuclear reactors is supplied by domestic and foreign producers, inventories held by utilities, and secondary market transactions such as producer-to-producer sales, utility-to-utility sales and loans, and utility-to-producer sales. The role of each is described in the following sections.

2.2.2.1 Domestic Production

Table 4-7 in Chapter 4 shows trends in domestic production of uranium concentrate from 1947 to 1986, by state. Total production was relatively constant at 10,500 to 12,500 tons per year until 1977, when it began an increase that peaked in 1980 at 21,852 tons. Production has declined almost every year since, reaching only 6,753 tons in 1986 [DOE 87b].

2.2.2.2 Imports

A second source of uranium is the import market. Until 1975, foreign uranium was effectively banned from U.S. markets by a Federal law prohibiting the enrichment of imports for domestic use. This restriction was lifted gradually after 1975, and was eliminated completely in 1984. From 1975 through 1977, imports amounted to a small portion of total domestic requirements, and U.S. exports actually exceeded imports in each year from 1978 through 1980. By 1986, however, imports supplied 44 percent of U.S. requirements. Table 4-10 in chapter 4 lists U.S. imports from 1974 through 1986 [DOE 87a].

Historically, the primary sources of U.S. uranium imports were Canada, South Africa and Australia. In 1986, 59 percent of U.S. uranium imports were from Canada, and 41 percent were from Australia and South Africa [DOE 87a].

Forecasts of import penetration call for the import share to grow through the 1990's. The Department of Energy projects that without government intervention, between the years 1990 and 2000 imports will range between 50 and 64 percent of domestic utility requirements, depending on demand.

2.2.2.3 Inventories

Utilities hold uranium inventories in order to meet changes in the scheduling of various stages of the fuel cycle, such as minor delays in deliveries of uranium feed. Uranium inventories also protect the utilities against disruption of nuclear fuel supplies. The average "forward coverage" currently desired by domestic utilities (in terms of forward reactor operating requirements) is 18 months for natural uranium (U_3O_8) and seven months for enriched uranium hexafluoride (UF_6) [DOE 85a]. Table 4-11 in chapter 4 lists inventories of commercially-owned natural and enriched uranium held in the United States as of December 31, 1984, 1985, and 1987. DOE-owned inventories are not included. The uranium inventory owned by utilities alone at the end of 1984 represented almost four years of forward coverage.

2.2.2.4 Secondary Market Transactions

The secondary market for uranium includes producer-to-producer sales, utility-to-utility sales and loans, and utility-to-producer sales. The secondary market, by definition, does not increase the supply of uranium, only the alternatives for purchasing it. As such, secondary transactions can have a significant impact on the demand for new production and on the year-to-year changes in inventories. The secondary market has been significant in recent years. During 1986, sales of 6,800 tons of U_3O_8 equivalent were made between domestic utilities and suppliers in the secondary market.

2.2.3 Financial Analysis

Selected financial data for the domestic uranium industry for 1982 to 1986 are shown in Table 4-15 in chapter 4. The data cover a subset of firms (the same firms for all years) that represent over 80 percent of the assets in the industry in each year. The firms included are those for which uranium operations could be separated from other aspects of the organization's business, and for which an acceptable level of consistency in financial reporting practices was available for all years.

As shown in Table 4-18 in chapter 4, net income accruing to the uranium industry was positive in only two years, 1982 and 1983. The returns on assets (net income divided by total assets) in these years were 0.7 and 1.4 percent respectively, and aggregate net earnings totalled $69.8 million. In 1984, 1985, and 1986, the returns on assets were -10.3, -21.6, and -2.3 percent, and aggregate net losses reached $765.7 million. The loss in 1984 alone was $304.7 million on revenues of $608.9 million. Thus, the aggregate loss for the five years was $695.9 million. In 1977, 146 firms were involved in domestic uranium exploration, 135 in mining and 26 in milling. In contrast, only 31 firms were actively engaged in exploration, 11 in mining and 5 in milling toward the end of 1986. Of these firms, only 27 percent had positive net income after meeting operating expenses and other obligations such as payment of taxes and recovery of depletion, depreciation and amortization. Many of the firms (55 percent) reported net losses; the remaining 18 percent either had left the industry or had no data to provide.

Most of the financial improvement in 1986 stemmed from the slowdown or the completion of writeoffs of discontinued operations, revaluation of assets and abandonments. The domestic uranium industry is significantly smaller than before, and its financial state will depend on higher product prices or demand [DOE 87a].

Company-specific information on uranium production, revenues, profits, and plans is provided in the following paragraphs. More detail is provided in Chapter 4.

2.2.3.1 Homestake Mining Company

Homestake Mining Company owns one conventional uranium mine and a 3400 ton per day mill in Grants, New Mexico. During 1984, production of uranium was reduced to the minimum level at which satisfactory unit costs could be maintained. Mine production has been confined to one mine operating on a five-day-week schedule for ten months of the year. Uranium concentrate was also recovered from solution mining and ion-exchange. In 1986, uranium accounted for 14 percent of the company's revenues, and 21 percent of operating earnings. The high profitability of the sector for the year is attributed to existing contracts, expiring in 1987, that provide for sale prices above current spot prices and production costs [AR 84, AR 85, AR 86].

2.2.3.2 Rio Algom

Rio Algom is a Canadian corporation engaged in the mining of a wide variety of materials, including copper, steel, and uranium. In 1986, uranium operations accounted for 26 percent of corporate revenue, but most (89 percent) was from Canadian production. In the United States, the company owns one uranium mine and a 750 ton per day mill in La Sal, Utah.

In 1986, the company produced 457 tons of uranium oxide from its Utah mine. The mine operated at approximately 50 percent of capacity in 1986, while the mill operated at capacity due to a significant amount of toll milling [AR 86].[1] In 1987, the La Sal mill produced about 350 tons of uranium oxide using both company ore and ore from the Thornberg mine. The mill was placed on standby in September of 1988, because the Lisbon and Thornberg mines' reserves were depleted [EPA 89].

2.2.3.3 Plateau Resources Limited

Plateau Resources, a wholly owned subsidiary of Consumers Power Co., was organized in 1976 to acquire, explore, and develop properties for the mining, milling, and sale of uranium. All operations were suspended in 1984 because of depressed demand and all uranium assets were written down by $46 million after taxes in 1984 and $21 million in 1985, to an estimated net realizable value of approximately $34 million. There is no assurance that the amount will ever be realized however.

2.2.3.4 Western Nuclear

Western Nuclear, a subsidiary of Phelps Dodge Corporation, owns two mine and mill complexes, one in Wyoming and one in Washington. The capacities of its mills are 1700 and 2000 tons per day, respectively. The Wyoming mill has been on standby since the early 1980s, and decommissioning is anticipated. The Washington complex operated intermittently from 1981 through 1984. In late 1984,

---

[1] "Toll milling" is the processing of ore from another company's mines on a contract basis.

Phelps Dodge wrote off its entire "Energy" operation, of which Western Nuclear was a major part [AR 84, AR 85].

2.2.4 Industry Forecast and Outlook

This section presents projections of total U.S. utility market requirements, domestic uranium production, from both conventional and non-conventional sources, imports, employment and electricity consumption. Developed for a 14-year period (1987-2000), these projections are considered "near term." A basic assumption of the near term projections is that current market conditions, as defined by the Department of Energy's Energy Information Administration (DOE,EIA), will continue unchanged through the end of this century. This section is based on the reference case projections in EIA's Domestic Uranium Mining and Milling Industry: 1986 Viability Assessment [DOE 87a].

2.2.4.1 Projections of Domestic Production

The EIA's Reference case[2] forecasts, for the 1987-2000 time period, are based on the output of EIA's economic model, Domestic Evaluation of Uranium Resources and Economic Analysis (EUREKA). The EUREKA model's methodology goes beyond the scope of this study; it is fully described in Appendix C of the 1986 Viability Assessment. The EIA examines future developments in the domestic uranium industry and in the domestic and international uranium markets under current market conditions and under certain hypothetical supply disruption scenarios[3]. The current market conditions are generally the same as those presented in Sections 4.2.1-4.2.4 of this study and are based on historical trends in the domestic uranium industry as outlined in both the Viability Assessment and the EIA's Uranium Industry Annual 1986.

---

[2] Prior to the *1986 Viability Assessment*, EIA published two reference cases: a Lower Reference case and an Upper Reference case, each with a low, a mean, and a high range of projected values. In 1986, however, only the Lower Reference case was published. It is referred to simply as the Reference case. As before, low, mean and high projected values were produced by EIA. This study uses the mean.

The Reference case in the *1986 Viability Assessment* uses the underlying assumptions for the Lower Reference case described in *Commercial Nuclear Power 1987: Prospects for the United States and the World* [DOE 87a].

[3] These scenarios, the "current disruption status" scenario and the "projected disruption status" scenario, are used to test the viability of the U.S. uranium industry, to examine the ability of this industry to respond to an abrogation of various fractions of contracts for uranium imports intended for domestic end use. Both of these bear only tangentially on this study and will not be discussed further here.

2.2.4.2 Near-Term Projections

Total domestic production of U_3O_8, from both conventional and non-conventional uranium sources, for 1980-1986 is shown in Table 4-18 of chapter 4, along with reference case projections for 1987-2000. Annual domestic production peaked at 21,900 short tons after milling in 1980, and declined to 6,750 short tons in 1986. Production is projected to remain below its 1980 peak. For example, EIA has projected domestic U_3O_8 production in 1992 at 6,450 short tons, while the output in the year 2000 is estimated to be 7,500 short tons. Annual domestic production from conventional mining sources (i.e., from milling ore obtained from underground or open-pit mines, which historically has accounted, on average, for roughly 70 percent of total annual domestic production) has fallen more steeply: from 85 percent in 1980 to 53 percent in 1985. However, it increased from its 1985 level of 3,275 short tons to 5,825 short tons in 1986. This increase was due to an increase in the U_3O_8 concentration of the ore milled in that year.

Changes in the market, such as the ban on imports of uranium ore or concentrate from South Africa and Namibia[4], could influence conventional production much more than non-conventional U_3O_8 production, because non-conventional U_3O_8 producers tend to have lower marginal costs of production than do conventional producers. Therefore, production from non-conventional sources tends to be less affected by fluctuations in uranium market prices. Wet process phosphoric acid, copper waste dumps, and bellyrium ores constitute by-product methods of production of U_3O_8. The second significant non-conventional source is in situ leaching. By-product and in situ leaching both accounted for 79 percent of the total non-conventional annual production of U_3O_8 in 1986. Other sources include mine water, and heap leaching, which accounted for the remaining 21 percent of total annual non-conventional production in 1986.

The Reference case EIA projections of domestic U_3O_8 production through the year 2000 are based on a unit by unit review of nuclear power plants that are new, operating, under construction, or units for which orders have been placed and for which licenses are currently being processed. Under EIA's Reference case, nuclear generating capacity is expected to increase from 94.0 GWe in 1987 to 103.0 GWe in the year 2000 (Table 4-19). Historical and forecast data of total enrichment feed deliveries (demand), net imports, and total production are graphed in Figure 4-1 [DOE 87a]. Historical data and reference case projections for conventional and non-conventional production of domestic uranium are plotted in Figure 4-2.

---

[4] The U.S. Congress passed the Comprehensive Anti-Apartheid Act of 1986 on October 2, 1986. Section 309 of that Act forbade the import into the United States of uranium ore or concentrate of South African of Namibian origin after January 1, 1987. However, natural or enriched uranium hexafluoride from these countries may be imported, according to a regulation issued by the U.S. Department of the Treasury on which the U.S. Nuclear Regulatory Commission has concurred [EPA 87b].

2.3 Current Emissions, Risk Levels, and Feasible Control Methods

2.3.1 Introduction

In this section, the current risks due to radon emissions from underground uranium mines are described, ways of reducing these risks are discussed and the effects of two alternative rules for reducing the risks to maximum exposed individuals due to radon emissions from uranium mines are estimated.

2.3.2 Current Emissions and Estimated Risk Levels

Due to the ongoing decline of the uranium industry, the list of firms in operation, shown in Table 2-1, has continued to shrink. As of the fall of 1988, fourteen mines were producing and one other, the Schwartzwalder mine owned by the Cotter Corporation, was on standby and was being explored. Three of the producing mines, Pigeon, Pinenut and Kanab North, all owned by Energy Fuels Nuclear, Inc., were breccia-pipe mines, which will be mined out in two to five years. Sheep Mountain #1 will operate for five more years. Only the Mt. Taylor mine, with an expected life of twenty years, has the possibility of operating for a significant amount of time. Section 23, owned by the Homestake Mining Company, has an expected life of only 1.25 years. Information regarding the expected life of the other eight mines is not available.

Estimates of current emissions and risk levels for these fifteen mines, ranked by maximum individual risk (MIR), are shown in Table 2-2. Although Section 23 has the highest rate of radon emissions, the highest individual risk is due to the La Sal mine and the highest population risk is due to emissions from the Schwartzwalder mine.

2.3.3 Control Technologies

2.3.3.1 Introduction

After extensive efforts to devise control technologies that would reduce the emissions of radon-222 from underground mines, it was concluded that no suitable technology is available [EPA 89]. The approaches discussed here seek to limit the emissions of the mines by restricting their days of operation and to reduce the risks from radon emissions to nearby populations by installing stacks that

Table 2-1. Currently Operating Underground Uranium Mines in the United States.

State/Mine	Company	Type	Expected Life (y)	Assumed Current Production Rate (MT/d)
Arizona				
Kanab North	Energy Fuels Nuclear, Inc	Breccia-pipe	6	270-360
Pigeon	Energy Fuels Nuclear, Inc	Breccia-pipe	6	270-360
Pinenut	Energy Fuels Nuclear, Inc	Breccia-pipe	3	270-360
Colorado				
Calliham	UMETCO Minerals Corp.	Modified Room and Pillar	NA	NA
Deremo-Snyder	UMETCO Minerals Corp.	Modified Room and Pillar	NA	280
King Soloman	UMETCO Minerals Corp.	Modified Room and Pillar	NA	350
Nil	UMETCO Minerals Corp.	Modified Room and Pillar	NA	50
Schwartzwalder	Cotter Corp.	Modified Room and Pillar with Vein Structure	Standby	0
Sunday	UMETCO Minerals Corp.	Modified Room and Pillar	NA	200
Wilson-Siverbell	UMETCO Minerals Corp.	Modified Room and Pillar	NA	90
New Mexico				
Mt. Taylor	Chevron Resources Co.	Modified Room and Pillar	20	544
Section 23	Homestake Mining Co.	Modified Room and Pillar	1.25	68
Utah				
La sal	UMETCO Minerals Corp.	Modified Room and Pillar	NA	160
Snowball-Pandora	UMETCO Minerals Corp.	Modified Room and Pillar	NA	54
Wyoming				
Sheep Mountain 1	U.S. Energy Co.	Random Drifting	5	220

NA: Information Not Available

Source: (EPA89)

TABLE 2-2 CURRENT RISK LEVELS DUE TO RADON-222
(Ranked by Maximum Individual Risk)

		Maximum Exposed Individual	Regional Exposure	
Mine	Annual Radon-222 Release (Ci/y)	Lifetime Cancer Risk	1980 Population w/in 80 km	Committed Fatal Cancers Per Yr (0-80 km)
La Sal	2460	4.4E-03	21,000	3.0E-03
Deremo-Snyder	960	1.7E-03	30,000	1.0E-03
Snowball-Pandora	2920	1.3E-03	21,000	4.0E-03
Schwartzwalder	6385	1.2E-03	1,800,000	7.0E-01
Calliham	260	1.1E-03	30,000	4.0E-04
Section 23	8894	4.1E-04	65,000	5.0E-02
King Solomon	2020	3.5E-04	67,000	5.0E-03
Wilson-Silverbell	790	3.4E-04	30,000	1.0E-03
Sunday	3120	3.3E-04	24,000	4.0E-03
Nil	690	7.3E-05	55,000	2.0E-03
Pigeon	2560	6.1E-05	7,800	2.0E-03
Mt. Taylor	2180	3.6E-05	50,000	3.0E-03
Kanab North	1640	2.4E-05	11,000	1.0E-03
Sheep Mountain No. 1	170	6.5E-06	5,200	2.0E-04
Pinenut	350	2.7E-06	8,300	2.0E-04
			TOTAL	7.8E-01

would reduce the higher concentrations of radon-222 at sites close to the mines. The proposed regulations would allow combinations of these measures, and other measures that may be developed in the future, so long as risk is reduced to acceptable levels.

Three alternative rules are under consideration and are discussed in this chapter. The first is to require mines to reduce emissions through partial shutdowns and stack installations such that the lifetime risk of cancer for the most exposed individual, also referred to as maximum individual risk (MIR), is under 3E-4. The second is to similarly reduce the MIR to below 1E-4. The third is to reduce the MIR to below 3E-5.

2.3.3.2 Alternative One: Maximum Individual Risk Under 1E-4

The first alternative rule is that mines should employ a combination of 1) a reduction of operating days per year to reduce annual radon-222 emissions and 2) construction of stacks to release radon-222 emissions from higher elevations such that the risk of fatal cancer to the most exposed individual is reduced to under 1E-4. Both of these measures have the effect of reducing the lifetime risk of fatal cancer to the most exposed individual.

While reduced operations are feasible, there are some complications in estimating the cost and the amount of emission reductions that would result. This is because the costs of temporarily closing a mine and maintaining it while it is closed are not clear. Some venting of the mine will be necessary for the safety of maintenance workers. This venting would affect the reduction of radon emissions that would be otherwise achieved. Estimating the cost of the vents is more straight forward. Analysis of the emission and risk levels due to alternative one, shown in Table 2-3, is based on the assumption that radon emissions are proportional to the percentage of time the mine is open.

Six of the mines -- Mt. Taylor, Nil, Pinenut, Sheep Mountain No. 1, Pigeon, and Kanab North -- can meet alternative one without reducing emissions or increasing stack height. Note that the Mt. Taylor mine already has a twenty meter stack.

In determining the measures to be taken to meet alternative one, the MIR for each combination of stack height (baseline, 10, 20, 30 and 60 meters) and reductions in emissions from zero to one hundred percent was calculated. For each stack height, the smallest emission reduction that reduced the MIR to the designated level was then determined. The least costly combination of emission reduction and stack height for each mine was selected for further analysis. This analysis is discussed more thoroughly in section 2.4.2 below.

Table 2-3: Alternative 1: Measures Taken and Their Effects on Maximum Exposed Individuals and Populations within 80 km

Alternative 1: MIR BELOW 3E-4

mine	Stack Height	Emission Reduction	MIR	Reduction from initial MIR	Annual Risk to Population within 80 km	Reduction in Population Risk
La Sal	0	95%	2.2E-04	4.2E-03	1.5E-04	2.9E-03
Schwartzwalder	0	75%	3.0E-04	9.0E-04	1.8E-01	5.3E-01
Calliham	0	75%	2.8E-04	8.3E-04	1.0E-04	3.0E-04
Deremo-Snyder	0	85%	2.6E-04	1.4E-03	1.5E-04	8.5E-04
Snowball-Pandora	0	80%	2.0E-04	1.1E-03	8.0E-04	3.2E-03
Wilson-Silverbell	0	15%	2.9E-04	5.1E-05	8.5E-04	1.5E-04
King Solomon	0	15%	3.0E-04	5.2E-05	4.3E-03	7.5E-04
Section 23	0	30%	2.9E-04	1.2E-04	3.5E-02	1.5E-02
Sunday	0	10%	3.0E-04	3.3E-05	3.6E-03	4.0E-04
Mt. Taylor	20	0%	3.6E-05	0.0E+00	3.0E-03	0.0E+00
Sheep Mountain No. 1	0	0%	6.5E-06	0.0E+00	2.0E-04	0.0E+00
Pinenut	0	0%	2.7E-06	0.0E+00	2.0E-04	0.0E+00
Kanab North	0	0%	2.4E-05	0.0E+00	1.0E-03	0.0E+00
Nil	0	0%	7.3E-05	0.0E+00	2.0E-03	0.0E+00
Pigeon	0	0%	6.1E-05	0.0E+00	2.0E-03	0.0E+00

2.3.3.3 Alternative Two: Maximum Individual Risk Under 1E-4

Table 2-4 describes the emissions and risk levels due to alternative two. Alternative two would require some mines to further reduce operations in order to additionally reduce cancer risks to the most exposed individuals. The same six mines that would not have to do anything under alternative one would still not have to do anything under alternative two.

2.3.3.4 Alternative Three: Maximum Individual Risk Under 3E-5

Table 2-5 describes the emission and risk levels due to alternative three. Alternative three would require some mines to further reduce operations or increase stack height in order to additionally reduce cancer risks to the maximum exposed individuals. Note that three mines -- Sheep Mountain No. 1, Kanab North, and Pinenut -- meet alternative three without any reduction of emissions or construction of stacks. The same issues as are involved in alternative one and two pertain to alternative three.

2.4 Analysis of Benefits and Costs

2.4.1 Introduction

In this section, the benefits and costs of the alternatives under consideration are examined. Benefits in terms of reductions of the risk of cancer to the most exposed individual and the 80 km population are demonstrated. Costs for alternative one and two and cost differentials between the base case and alternatives one and two are calculated. Finally, the effects of various assumptions on the conclusions drawn in the above are assessed.

2.4.2 Least-Cost Control Strategies for Meeting Alternatives One, Two and Three

In order to complete the analysis of alternatives one, two, and three, it is necessary to determine which combination of control parameters (emission reductions and stack heights) the mines' operators would select. The rule allows them a set of options; the analysis assumes they would choose the least costly option that meets the rule. Tables 2-3, 2-4, and 2-5 above show the outcome of the analysis in terms of the combination of emission reduction and stack height selected, reductions in MIR and population risk. This section discusses the details of the analysis.

The example used in this discussion is Pigeon Mine. Table 2-6 shows a matrix of maximum individual risks (MIRs) for various combinations of emission reductions and stack heights for Pigeon

Table 2-4: Alternative 2: Measures Taken and Their Effects on Maximum Exposed Individuals and Populations within 80 km

Alternative 2: MIR BELOW 1E-4

mine	Stack Height	Emission Reduction	MIR	Reduction from initial MIR	Annual Risk to Population within 80 km	Reduction in Population Risk
La Sal	0	100%	0.0E+00	4.4E-03	0.0E+00	3.0E-03
Schwartzwalder	0	95%	6.0E-05	1.1E-03	3.5E-02	6.7E-01
Calliham	0	95%	5.5E-05	1.0E-03	2.0E-05	3.8E-04
Deremo-Snyder	0	95%	8.5E-05	1.6E-03	5.0E-05	9.5E-04
Snowball-Pandora	0	95%	6.5E-05	1.2E-03	2.0E-04	3.8E-03
Wilson-Silverbell	0	75%	8.5E-05	2.6E-04	2.5E-04	7.5E-04
King Solomon	0	75%	8.8E-05	2.6E-04	1.3E-03	3.8E-03
Section 23	0	80%	6.2E-05	3.5E-04	1.0E-02	4.0E-02
Sunday	0	70%	9.9E-05	2.3E-04	1.2E-03	2.8E-03
Mt. Taylor	20	0%	3.6E-05	0.0E+00	3.0E-03	0.0E+00
Sheep Mountain No. 1	0	0%	6.5E-06	0.0E+00	2.0E-04	0.0E+00
Pinenut	0	0%	2.7E-06	0.0E+00	2.0E-04	0.0E+00
Kanab North	0	0%	2.4E-05	0.0E+00	1.0E-03	0.0E+00
Nil	0	0%	7.3E-05	0.0E+00	2.0E-03	0.0E+00
Pigeon	0	0%	6.1E-05	0.0E+00	2.0E-03	0.0E+00

Table 2-5: **Alternative 3: Measures Taken and Their Effects on Maximum Exposed Individuals and Populations within 80 km**

Alternative 3: MIR BELOW 3E-5

mine	Stack Height	Emission Reduction	MIR	Reduction from initial MIR	Annual Risk to Population within 80 km	Reduction in Population Risk
La Sal	0	100%	0.0E+00	4.4E-03	0.0E+00	3.0E-03
Schwartzwalder	0	100%	0.0E+00	1.2E-03	0.0E+00	7.0E-01
Calliham	0	100%	0.0E+00	1.1E-03	0.0E+00	4.0E-04
Deremo-Snyder	0	100%	0.0E+00	1.7E-03	0.0E+00	1.0E-03
Snowball-Pandora	0	100%	0.0E+00	1.3E-03	0.0E+00	4.0E-03
Wilson-Silverbell	0	95%	1.7E-05	3.2E-04	5.0E-05	9.5E-04
King Solomon	0	95%	1.8E-05	3.3E-04	2.5E-04	4.8E-03
Section 23	0	95%	2.1E-05	3.9E-04	2.5E-03	4.8E-02
Sunday	0	95%	1.7E-05	3.1E-04	2.0E-04	3.8E-03
Mt. Taylor	30	0%	2.7E-05	9.0E-06	3.0E-03	0.0E+00
Sheep Mountain No. 1	0	0%	6.5E-06	0.0E+00	2.0E-04	0.0E+00
Pinenut	0	0%	2.7E-06	0.0E+00	2.0E-04	0.0E+00
Kanab North	0	0%	2.4E-05	0.0E+00	1.0E-03	0.0E+00
Nil	0	60%	2.9E-05	4.4E-05	8.0E-04	1.2E-03
Pigeon	60	0%	3.0E-05	3.1E-05	2.0E-03	0.0E+00

Table 2-6: Matrix of MIRs as Stack Height and Emissions at Pigeon Mine Vary

RISK TO NEAREST INDIVIDUAL (MIR)

REDUCTION IN EMISSION LEVEL	STACK HEIGHT					REDUCTION IN EMISSION LEVEL
	0 M	10 M	20 M	30 M	60 M	
100%	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	100%
95%	3.1E-06	3.0E-06	2.8E-06	2.5E-06	1.5E-06	95%
90%	6.1E-06	5.9E-06	5.6E-06	5.0E-06	3.0E-06	90%
85%	9.2E-06	8.9E-06	8.4E-06	7.5E-06	4.5E-06	85%
80%	1.2E-05	1.2E-05	1.1E-05	1.0E-05	6.0E-06	80%
75%	1.5E-05	1.5E-05	1.4E-05	1.3E-05	7.5E-06	75%
70%	1.8E-05	1.8E-05	1.7E-05	1.5E-05	9.0E-06	70%
65%	2.1E-05	2.1E-05	2.0E-05	1.7E-05	1.1E-05	65%
60%	2.4E-05	2.4E-05	2.2E-05	2.0E-05	1.2E-05	60%
55%	2.7E-05	2.7E-05	2.5E-05	2.3E-05	1.4E-05	55%
50%	3.1E-05	3.0E-05	2.8E-05	2.5E-05	1.5E-05	50%
45%	3.4E-05	3.2E-05	3.1E-05	2.8E-05	1.7E-05	45%
40%	3.7E-05	3.5E-05	3.4E-05	3.0E-05	1.8E-05	40%
35%	4.0E-05	3.8E-05	3.6E-05	3.3E-05	2.0E-05	35%
30%	4.3E-05	4.1E-05	3.9E-05	3.5E-05	2.1E-05	30%
25%	4.6E-05	4.4E-05	4.2E-05	3.8E-05	2.3E-05	25%
20%	4.9E-05	4.7E-05	4.5E-05	4.0E-05	2.4E-05	20%
15%	5.2E-05	5.0E-05	4.8E-05	4.3E-05	2.6E-05	15%
10%	5.5E-05	5.3E-05	5.0E-05	4.5E-05	2.7E-05	10%
5%	5.8E-05	5.6E-05	5.3E-05	4.8E-05	2.9E-05	5%
0%	6.1E-05	5.9E-05	5.6E-05	5.0E-05	3.0E-05	0%
	0 M	10 M	20 M	30 M	60 M	

Mine. For each stack height, MIRs increase as reductions in emission levels decrease. For alternative two, MIR < 1e-4, looking down the column for a stack height of zero (i.e., the baseline stack height), the table shows the rule can be met at Pigeon Mine with no emission reductions. The largest number in the column is less than 1E-4. Table 2-7 shows the reduction in emission levels needed to comply with alternatives one, two, and three. For each stack height, alternatives one and two can be satisfied with no emission reductions. When the third alternative is considered, looking down the first column of Table 2-6 indicates that a fifty-five percent reduction in emissions is needed to meet the 3E-5 limit. With a stack height of ten meters, a fifty percent reduction is needed; with a stack height of twenty meters, a fifty percent reduction is again needed; for thirty meters, a forty-five percent reduction suffices; and for a sixty meter stack, no emission reduction is required.

The next step is to determine associated costs. Table 2-8 shows the cost for each stack height and emission reduction combination. These costs are summarized in table 2-7. The costs of constructing stacks of various heights were obtained from [SC89]. The other cost component is the present value of the opportunity cost to the mine owners of removing the various quantities of uranium from the market due to shutdowns. It was assumed, based on historical records, that all but two percent of mine revenues are used to pay obligations to workers, capital improvements and other costs of doing business. Also, the price of uranium at the mines was assumed to be $110.23 per MT. The opportunity cost calculations were done without discounting. This accentuates the relative value of uranium mined in future years. It is therefore interesting that tables 2-3, 2-4, and 2-5 indicate that partial and sometimes complete shutdowns are less costly to mine owners than building stacks. Only Pigeon Mine and Mt. Taylor Mine would opt for stack construction, and Mt. Taylor already has a twenty meter stack.

In the case of Pigeon Mine the value of the uranium that could be mined if a sixty meter stack were installed was sufficient to justify building the stack. Figure 2-1 (based on Table 2-7) shows that the overall cost of complying with alternative three at Pigeon Mine at first remains relatively constant, reaching a maximum at twenty meters, and then declines sharply after thirty meters. Sixty meters is the optimal stack height for Pigeon Mine under alternative three because it meets the rule. A taller stack would gain nothing because it would not allow any greater production of uranium.

Analyses similar to that done for Pigeon Mine were also performed for the other fourteen mines. These are summarized in Tables 2-3, 2-4, and 2-5 above.

TABLE 2-7: Pigeon Mine, Summary of Risk Reductions and Costs

risk to nearest individual
for MIR <= 3e-4

STACK HEIGHT (in meters)	REDUCTION IN EMISSION LEVEL	resulting MIR	cost
0	0%	6.1E-05	$0
10	0%	5.9E-05	$31,200
20	0%	5.6E-05	$80,500
30	0%	5.0E-05	$146,600
60	0%	3.0E-05	$291,400
		Minimum cost:	$0

risk to nearest individual
for MIR <= 1e-4

STACK HEIGHT (in meters)	REDUCTION IN EMISSION LEVEL	resulting MIR	cost
0	0%	6.1E-05	$0
10	0%	5.9E-05	$31,200
20	0%	5.6E-05	$80,500
30	0%	5.0E-05	$146,600
60	0%	3.0E-05	$291,400
		Minimum cost:	$0

risk to nearest individual
for MIR <= 3e-5

STACK HEIGHT (in meters)	REDUCTION IN EMISSION LEVEL	resulting MIR	cost
0	55%	2.7E-05	$836,464
10	50%	3.0E-05	$791,622
20	50%	2.8E-05	$840,922
30	45%	2.8E-05	$830,979
60	0%	3.0E-05	$291,400
		Minimum cost:	$291,400

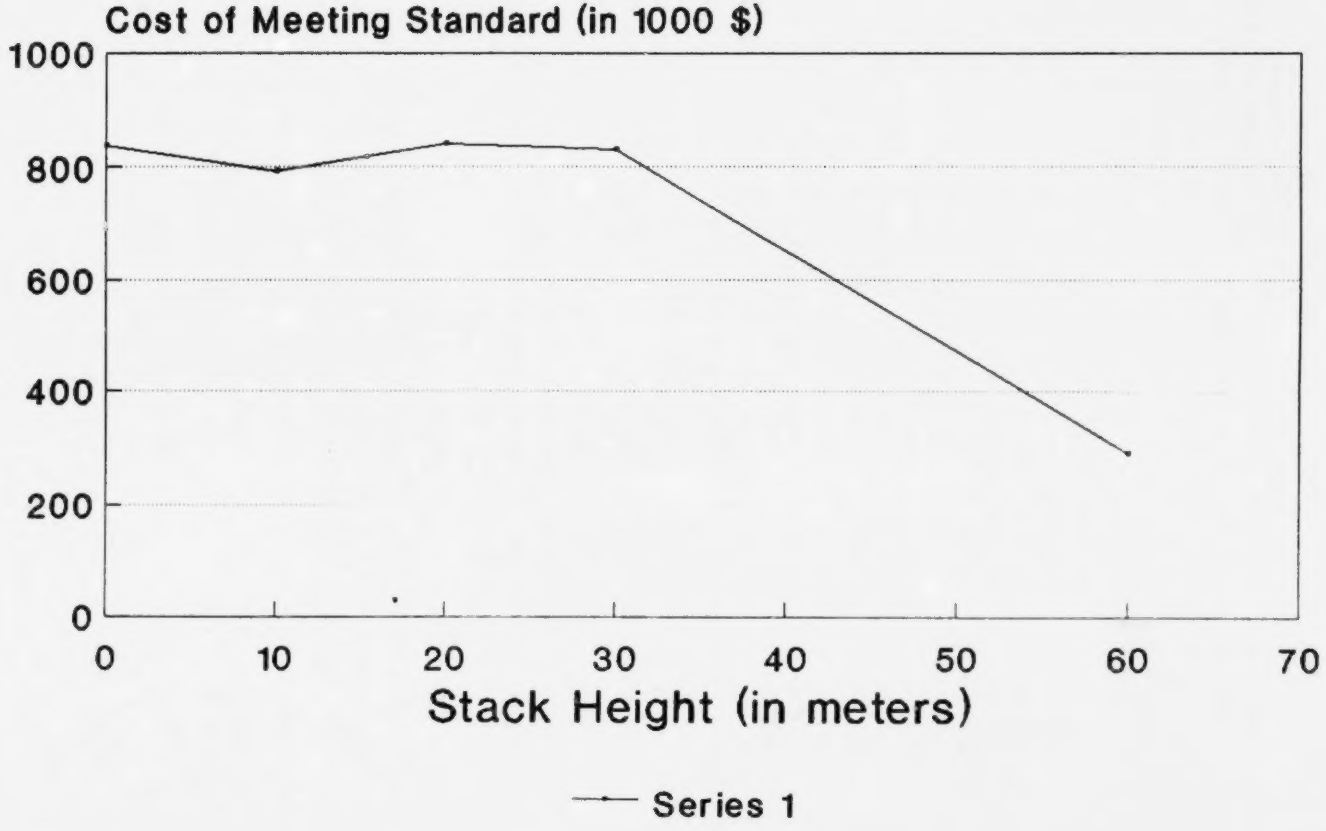
TABLE 2-8: Matrix of Costs of Various Combinations of Stack Height and Shutdown Time for Pigeon Mine.

The last column is the cost of shutdown by percent of a one year shutdown

The first row is the cost of constructing stacks of various heights. Other rows are sums of costs of shutdown and of constructing stacks.

0 M	10 M	20 M	30 M	60 M	percent of year shutdown	cost of shutdown
$0	$31,200	$80,500	$146,600	$291,400	0%	$0
$76,042	$107,242	$156,542	$222,642	$367,442	5%	$76,042
$152,084	$183,284	$232,584	$298,684	$443,484	10%	$152,084
$228,126	$259,326	$308,626	$374,726	$519,526	15%	$228,126
$304,169	$335,369	$384,669	$450,769	$595,569	20%	$304,169
$380,211	$411,411	$460,711	$526,811	$671,611	25%	$380,211
$456,253	$487,453	$536,753	$602,853	$747,653	30%	$456,253
$532,295	$563,495	$612,795	$678,895	$823,695	35%	$532,295
$608,337	$639,537	$688,837	$754,937	$899,737	40%	$608,337
$684,379	$715,579	$764,879	$830,979	$975,779	45%	$684,379
$760,422	$791,622	$840,922	$907,022	$1,051,822	50%	$760,422
$836,464	$867,664	$916,964	$983,064	$1,127,864	55%	$836,464
$912,506	$943,706	$993,006	$1,059,106	$1,203,906	60%	$912,506
$988,548	$1,019,748	$1,069,048	$1,135,148	$1,279,948	65%	$988,548
$1,064,590	$1,095,790	$1,145,090	$1,211,190	$1,355,990	70%	$1,064,590
$1,140,632	$1,171,832	$1,221,132	$1,287,232	$1,432,032	75%	$1,140,632
$1,216,675	$1,247,875	$1,297,175	$1,363,275	$1,508,075	80%	$1,216,675
$1,292,717	$1,323,917	$1,373,217	$1,439,317	$1,584,117	85%	$1,292,717
$1,368,759	$1,399,959	$1,449,259	$1,515,359	$1,660,159	90%	$1,368,759
$1,444,801	$1,476,001	$1,525,301	$1,591,401	$1,736,201	95%	$1,444,801
$1,520,843	$1,552,043	$1,601,343	$1,667,443	$1,812,243	100%	$1,520,843

FIGURE 2-1: PIGEON MINE, CONTROL COSTS BY STACK HEIGHT, MIR ‹ 3E-5



2.4.3 Benefits of Control Alternatives

Tables 2-9, 2-10, and 2-11 list the health benefits of alternatives one, two, and three relative to the baseline and relative to each other. The benefits are in terms of reductions in the risk of fatal cancer to the most exposed individual and the incidence of fatal cancer in the 80 km population. Alternative one will reduce the highest MIR from 4.4E-3 to 9.9E-5, a reduction of 4.3E-3. Alternative two also eliminates the highest MIR (4.4E-3) and leaves the same uncontrolled mine as the new contributor to the highest MIR which is again 9.9E-5. Alternative three will reduce the highest MIR from 4.4E-3 to 3.0E-5, a reduction of 4.4E-3. With regard to the 80 km population, alternative one will reduce the incidence of fatal cancers from 7.8E-1 to 2.3E-1, a reduction of 5.5E-1. Alternative two will reduce the incidence of fatal cancers from 7.8E-1 to 5.9E-2, a reduction of 7.2E-1 cases annually relative to the baseline incidence and a reduction of 1.7E-1 relative to alternative one. For alternative three the resulting incidence of fatal cancer will be 1.0E-2, an annual reduction of 7.7E-1 relative to the baseline incidence and of 4.9E-2 relative to alternative two. The greatest reduction in risk to the 80 km population at an individual mine will be experienced at Schwartzwalder Mine for all three alternatives. Schwartzwalder's reduction in risk to the 80 km population under alternative one will be 5.3E-1 deaths avoided annually. For alternative two the reduction is 6.7E-1 and for alternative three it is 7.0E-1.

Six mines will have no reductions in MIR or risk to the 80 km population under alternatives one and two because they already meet the 1E-4 level. Similarly under option three, three mines already meet the 3E-5 level. Applying alternative three to two other mines will reduce their MIRs, but will have no effect on the risk to the 80 km population. At these two mines, stack heights will be raised, but emissions will not be reduced.

2.4.4 Costs of Control Alternatives

In this section the aggregated costs of alternatives one, two, and three are analyzed. The economic effects of the timing of costs are evaluated using the net present value of the cost stream. Tables 2-12, 2-13, and 2-14 show the net present value of the cost streams for controlling emissions and ambient concentrations during the remaining life of each mine. This is calculated using net discount rates of zero, one, five, and ten percent.

In calculating the net present value, it was assumed that lower annual production rates would prolong the life of the mine. The costs for each year in which output restrictions are binding include the difference between revenues from operating at full capacity and at restricted capacity. When restrictions are binding, the revenues from those additional years of production are added to the end

Table 2-9: Health Benefits Due to Alternative One

	Initial Risk of Fatal Cancer		ALTERNATIVE 1: MIR BELOW 3E-4			
mine	Maximum Individual Risk	Committed Fatal Cancers Per Yr (0-80 km)	MIR	Reduction in MIR	Annual Risk to Population within 80 km	Reduction in Population Risk
La Sal	4.4E-03	3.0E-03	0.0E+00	4.4E-03	1.5E-04	2.9E-03
Calliham	1.1E-03	4.0E-04	5.5E-05	1.0E-03	1.0E-04	3.0E-04
Deremo-Snyder	1.7E-03	1.0E-03	8.5E-05	1.6E-03	1.5E-04	8.5E-04
Schwartzwalder	1.2E-03	7.0E-01	6.0E-05	1.1E-03	1.7E-01	5.3E-01
Snowball-Pandora	1.3E-03	4.0E-03	6.5E-05	1.2E-03	8.0E-04	3.2E-03
King Solomon	3.5E-04	5.0E-03	8.8E-05	2.6E-04	4.3E-03	7.5E-04
Wilson-Silverbell	3.4E-04	1.0E-03	8.5E-05	2.6E-04	8.5E-04	1.5E-04
Section 23	4.1E-04	5.0E-02	6.2E-05	3.5E-04	3.5E-02	1.5E-02
Sunday	3.3E-04	4.0E-03	9.9E-05	2.3E-04	3.6E-03	4.0E-04
Mt. Taylor	3.6E-05	3.0E-03	3.6E-05	0.0E+00	3.0E-03	0.0E+00
Nil	7.3E-05	2.0E-03	7.3E-05	0.0E+00	2.0E-03	0.0E+00
Pinenut	2.7E-06	2.0E-04	2.7E-06	0.0E+00	2.0E-04	0.0E+00
Sheep Mountain No. 1	6.5E-06	2.0E-04	6.5E-06	0.0E+00	2.0E-04	0.0E+00
Pigeon	6.1E-05	2.0E-03	6.1E-05	0.0E+00	2.0E-03	0.0E+00
Kanab North	2.4E-05	1.0E-03	2.4E-05	0.0E+00	1.0E-03	0.0E+00
	Totals:	7.8E-01			2.3E-01	5.5E-01

Table 2-10: Health Benefits Due to Alternative Two

ALTERNATIVE 2: MIR BELOW 1E-4

		Reduction in MIR		Annual Risk to	Reduction in Population Risk	
mine	MIR	Relative to Base	Relative to Alt. 1	Population within 80 km	Relative to Base	Relative to Alt. 1
La Sal	0.0E+00	4.4E-03	0.0E+00	0.0E+00	3.0E-03	1.5E-04
Calliham	5.5E-05	1.0E-03	0.0E+00	2.0E-05	3.8E-04	8.0E-05
Deremo-Snyder	8.5E-05	1.6E-03	0.0E+00	5.0E-05	9.5E-04	1.0E-04
Schwartzwalder	6.0E-05	1.1E-03	0.0E+00	3.5E-02	6.7E-01	1.4E-01
Snowball-Pandora	6.5E-05	1.2E-03	0.0E+00	2.0E-04	3.8E-03	6.0E-04
King Solomon	8.8E-05	2.6E-04	0.0E+00	1.2E-03	3.8E-03	3.0E-03
Wilson-Silverbell	8.5E-05	2.6E-04	0.0E+00	2.5E-04	7.5E-04	6.0E-04
Section 23	6.2E-05	3.5E-04	0.0E+00	1.2E-02	3.8E-02	2.3E-02
Sunday	9.9E-05	2.3E-04	0.0E+00	1.2E-03	2.8E-03	2.4E-03
Mt. Taylor	3.6E-05	0.0E+00	0.0E+00	3.0E-03	0.0E+00	0.0E+00
Nil	7.3E-05	0.0E+00	0.0E+00	2.0E-03	0.0E+00	0.0E+00
Pinenut	2.7E-06	0.0E+00	0.0E+00	2.0E-04	0.0E+00	0.0E+00
Sheep Mountain No. 1	6.5E-06	0.0E+00	0.0E+00	2.0E-04	0.0E+00	0.0E+00
Pigeon	6.1E-05	0.0E+00	0.0E+00	2.0E-03	0.0E+00	0.0E+00
Kanab North	2.4E-05	0.0E+00	0.0E+00	1.0E-03	0.0E+00	0.0E+00
Totals:				5.9E-02	7.2E-01	1.7E-01

Table 2-11: Health Benefits Due to Alternative Three

ALTERNATIVE 3: MIR BELOW 3E-5

		Reduction in MIR		Annual Risk to	Reduction in Population Risk	
mine	MIR	Relative to Base	Relative to Alt. 2	Population within 80 km	Relative to Base	Relative to Alt. 2
La Sal	0.0E+00	4.4E-03	0.0E+00	0.0E+00	3.0E-03	0.0E+00
Calliham	0.0E+00	1.1E-03	5.5E-05	0.0E+00	4.0E-04	2.0E-05
Deremo-Snyder	0.0E+00	1.7E-03	8.5E-05	0.0E+00	1.0E-03	5.0E-05
Schwartzwalder	0.0E+00	1.2E-03	6.0E-05	0.0E+00	7.0E-01	3.5E-02
Snowball-Pandora	0.0E+00	1.3E-03	6.5E-05	0.0E+00	4.0E-03	2.0E-04
King Solomon	1.8E-05	3.3E-04	7.0E-05	2.5E-04	4.8E-03	1.0E-03
Wilson-Silverbell	1.7E-05	3.2E-04	6.8E-05	5.0E-05	9.5E-04	2.0E-04
Section 23	2.1E-05	3.9E-04	4.1E-05	2.5E-03	4.8E-02	1.0E-02
Sunday	1.7E-05	3.1E-04	8.2E-05	2.0E-04	3.8E-03	1.0E-03
Mt. Taylor	2.7E-05	9.0E-06	9.0E-06	3.0E-03	0.0E+00	0.0E+00
Nil	2.9E-05	4.4E-05	4.4E-05	8.0E-04	1.2E-03	1.2E-03
Pinenut	2.7E-06	0.0E+00	0.0E+00	2.0E-04	0.0E+00	0.0E+00
Sheep Mountain No. 1	6.5E-06	0.0E+00	0.0E+00	2.0E-04	0.0E+00	0.0E+00
Pigeon	3.0E-05	3.1E-05	3.1E-05	2.0E-03	0.0E+00	0.0E+00
Kanab North	2.4E-05	0.0E+00	0.0E+00	1.0E-03	0.0E+00	0.0E+00
Totals:				1.0E-02	7.7E-01	4.9E-02

Table 2-12: Costs of Alternative One

Uranium Ore Price at Mine: $110.23 per MT   Expected Rate of Return: 2%

Mine ID	Stack Height	Emission Reduction	Expected Life (in years)	Ore Production Rate (MT/day)	Annual Opportunity Cost	Stack Cost	NPV of Alternative over life of mine at a discount rate of 0%	1%	5%	10%
La Sal	0	95%	7	160	$122,311	0	$856,178	$831,163	$743,125	$655,008
Calliham	0	75%		(a)	$0 (a)	0	$0	$0	$0	$0
Deremo-Snyder	0	85%	7	280	$191,514	0	$1,340,595	$1,301,426	$1,163,578	$1,025,605
Schwartzwalder	0	75%	standby	0	$0	0	$0	$0	$0	$0
Snowball-Pandora	0	80%	7	54	$34,762	0	$243,335	$236,225	$211,204	$186,160
King Solomon	0	15%	7	350	$42,246	0	$295,720	$287,079	$256,672	$226,236
Wilson-Silverbell	0	15%	7	90	$10,863	0	$76,042	$73,820	$66,001	$58,175
Section 23	0	30%	1.25	68	$16,415	0	$20,519	$20,479	$20,324	$20,146
Sunday	0	10%	7	200	$16,094	0	$112,655	$109,364	$97,780	$86,185
Mt. Taylor	20	0%	20	544	$0	0	$0	$0	$0	$0
Nil	0	0%	7	50	$0	0	$0	$0	$0	$0
Pinenut	0	0%	3	315	$0	0	$0	$0	$0	$0
Sheep Mountain no. 1	0	0%	5	220	$0	0	$0	$0	$0	$0
Pigeon	0	0%	6	315	$0	0	$0	$0	$0	$0
Kanab North	0	0%	6	315	$0	0	$0	$0	$0	$0

(a) no information available regarding production activity at Calliham.

Table 2-13: Costs of Alternative Two

Uranium Ore Price at Mine: $110.23 per MT   Expected Rate of Return: 2%

Mine ID	Stack Height	Emission Reduction	Expected Life (in years)	Ore Production Rate (MT/day)	Annual Opportunity Cost	Stack Cost	NPV of Alternative over life of mine at a discount rate of 0%	1%	5%	10%
La Sal	0	100%	7	160	$128,749	0	$901,240	$874,908	$782,237	$689,483
Calliham	0	95%		(a)	$0 (a)	0	$0	$0	$0	$0
Deremo-Snyder	0	95%	7	280	$214,045	0	$1,498,312	$1,454,535	$1,300,469	$1,146,265
Schwartzwalder	0	95%	standby	0	$0	0	$0	$0	$0	$0
Snowball-Pandora	0	95%	7	54	$41,280	0	$288,960	$280,517	$250,805	$221,065
King Solomon	0	75%	7	350	$211,228	0	$1,478,598	$1,435,397	$1,283,358	$1,131,182
Wilson-Silverbell	0	75%	7	90	$54,316	0	$380,211	$369,102	$330,006	$290,875
Section 23	0	75%	1.25	68	$41,039	0	$51,298	$51,197	$50,810	$50,366
Sunday	0	70%	7	200	$112,655	0	$788,585	$765,545	$684,457	$603,297
Mt. Taylor	20	0%	20	544	$0	0	$0	$0	$0	$0
Nil	0	0%	7	50	$0	0	$0	$0	$0	$0
Pinenut	0	0%	3	315	$0	0	$0	$0	$0	$0
Sheep Mountain no. 1	0	0%	5	220	$0	0	$0	$0	$0	$0
Pigeon	0	0%	6	315	$0	0	$0	$0	$0	$0
Kanab North	0	0%	6	315	$0	0	$0	$0	$0	$0

(a) no information available regarding production activity at Calliham.

Table 2-14: Costs of Alternative Three

Uranium Ore Price at Mine: $110.23 per MT Expected Rate of Return: 2%

Mine ID	Stack Height	Emission Reduction	Expected Life (in years)	Ore Production Rate (MT/day)	Annual Opportunity Cost	Stack Cost	NPV of Alternative over life of mine at a discount rate of 0%	1%	5%	10%
La Sal	0	100%	7	160	$128,749	0	$901,240	$874,908	$782,237	$689,483
Calliham	0	100%		(a)	$0 (a)	0	$0	$0	$0	$0
Deremo-Snyder	0	100%	7	280	$225,310	0	$1,577,171	$1,531,090	$1,368,915	$1,206,594
Schwartzwalder	0	100%	standby	0	$0	0	$0	$0	$0	$0
Snowball-Pandora	0	100%	7	54	$43,453	0	$304,169	$295,282	$264,005	$232,700
King Solomon	0	95%	7	350	$267,556	0	$1,872,890	$1,818,169	$1,625,586	$1,432,831
Wilson-Silverbell	0	95%	7	90	$68,800	0	$481,600	$467,529	$418,008	$368,442
Section 23	0	95%	1.25	68	$51,982	0	$64,978	$64,849	$64,359	$63,796
Sunday	0	95%	7	200	$152,889	0	$1,070,223	$1,038,954	$928,907	$818,761
Mt. Taylor	30	0%	20	544	$0	$425,500	$425,500	$425,500	$425,500	$425,500
Nil	0	60%	7	50	$24,140	0	$168,983	$164,045	$146,669	$129,278
Pinenut	0	0%	3	315	$0	0	$0	$0	$0	$0
Sheep Mountain no. 1	0	0%	5	220	$0	0	$0	$0	$0	$0
Pigeon	60	0%	6	315	$0	$291,400	$291,400	$291,400	$291,400	$291,400
Kanab North	0	0%	6	315	$0	0	$0	$0	$0	$0

(a) no information available regarding production activity at Calliham.

of the time stream. The mine with the highest cost is Deremo-Snyder Mine, under alternatives one and two, and King Solomon Mine under alternative three.

2.5 Industry Cost and Economic Impact Analysis

2.5.1 Introduction

In this section the effects of the alternatives analyzed on economic entities are considered. This includes assessing the relative impact of regulation on production costs, identifying which sectors of the economy might experience adverse (or beneficial) economic effects, and the potential of the regulation to affect small economic entities, such as small firms or small counties.

2.5.2 Production Cost Impacts

For purposes of illustration, these costs can be compared with the assumed return on uranium mining of 2 percent, based on the experience of the last decade. Also, the trend towards closing all mines indicates that profits may well be insufficient to sustain operations in the industry and any additional costs may speed the demise of the mines.

2.5.3 Economic Impact Analysis

Although the cost of regulating uranium mines could result in mine closures, the effects of these closures would be isolated to a small group of people -- the stockholders of the corporations who own the mines, the 230 miners considered in Table 2-15 who currently work in six of the mines, and the miners in the other mines for which no data was available. The employment and community situation at the other mines, though undocumented, is likely to be similar to that for the mines represented in Table 2-15. The effects of mine closure would not spread to the larger economy because 1) in the depressed market for uranium there are other producers of ore -- U.S. surface mines, by-product producers, and foreign mines -- who could continue to meet the current price and to respond competitively in case of increased demand and 2) the miners live in different counties and constitute a small proportion of workers in each.

As discussed in section 2.2, most underground uranium mines are subsidiaries of large corporations. Most of the direct costs of compliance will be borne by stockholders or owners. Because operators of underground uranium mines currently have little or no monopoly power they will not be able to pass these costs on to the electric power industry.

Table 2-16 shows the number of miners at each of the six mines along with the total population in the respective county. It also shows the number of mining establishments in the county and contrasts

TABLE 2-15: Number of Miners and Shifts Per Day by Mine For the Six Mines Where Information Is Available

Mine	Shifts/Day	Personnel
Schwartzwalder	2	31
Section 23	1	27
Mt. Taylor	2	57
Pigeon	3	38
Kanab North	3	42
Pinenut	3	35
	TOTAL	230

TABLE 2-16: Number of Miners and Mining Operations by County For the Six Mines Where Information Is Available

Mine	County	County Population	Number of Mine Workers	Total Establish-ments	Mining Establish-ments
Schwartzwalder	Jefferson	427400	31	10387	7
Section 23	Grant	na	27	580	10
	Cibola	23000	na	na	na
Mt. Taylor	McKinley	65800	57	921	4
Pigeon	Coconino	86100	38	2101	4
Kanab North	Coconino	86100	42	2101	4
Pinenut	Mohave	76600	35	1827	d

d = withheld to prevent disclosure of private information
na = not available

Sources: County Business Patterns, 1986
Bureau of Census, Personal Communication

that with the total number of workplaces. Because the number of miners involved is such a small proportion of the overall population, no effect on unemployment rates is expected. The only ripple effect would be the effect of mine closure on uranium mill employees who are also very small in number.

2.5.4 Regulatory Flexibility Analysis

As shown in the previous sections, the major effects of the regulations will fall on relatively large entities, the corporations that own the mines. Effects on unemployment rates in counties where the mines are located will be unmeasurable, since the miners represent well under one percent of the county populations.

REFERENCES

AR84 The annual reports of all uranium-producing companies were examined for the years 1976-1986. The reference, AR, is followed by a date. The specific company reference is to be found in the text.

AR85 The annual reports of all uranium-producing companies were examined for the years 1976-1986. The reference, AR, is followed by a date. The specific company reference is to be found in the text.

AR86 The annual reports of all uranium-producing companies were examined for the years 1976-1986. The reference, AR, is followed by a date. The specific company reference is to be found in the text.

DOE87a Department of Energy, *Domestic Uranium Mining and Milling Industry: 1986 Viability Assessment*, DOE/EIA-0477(86), November 23, 1987.

DOE87b Department of Energy, *Uranium Industry Annual 1986*, DOE/EIA-0478(86), October 9, 1987.

EPA 89 *Risk Assessment*, Vol.2.

JFA85a Jack Faucett Associates, *Economic Profile of the Uranium Mining Industry*. Prepared for U.S. Environmental Protection Agency, January 1985.

CHAPTER 3

INACTIVE URANIUM MILL TAILINGS

3. INACTIVE MILL TAILINGS

3.1 Introduction and Summary

The inactive uranium mill tailings source category is comprised of tailings and other wastes at 24 former processing sites designated as Title I sites under the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978. Radon-222, the decay product of the residual radium-226 in the tailings, is emitted to the air from the tailings. Radon emissions from licensed uranium mill tailings sites are addressed in Chapter 4.

The purpose of this chapter is to examine the costs, benefits, and economic impacts of reducing the maximum allowable levels of radon-222 emissions after closure from the 20 $pCi/m^2/sec$ limit established under UMTRCA. Options that are evaluated include reducing radon-222 emissions to a maximum of 6 $pCi/m^2/sec$, and to a maximum of 2 $pCi/m^2/sec$.

The remainder of this introduction provides a brief summary of the rulemaking history and the current regulations. A profile of the inactive uranium milling industry is given in Section 3.2. Section 3.3 addresses current emissions, risk levels and feasible control methods. Section 3.4 provides estimated benefits and costs of the proposed options. The economic impacts are considered in Section 3.5.

3.1.1 Rulemaking History and Current Regulations

In enacting the UMTRCA (Public Law 95-604, 42 USC 7901), Congress found that:

- "Uranium mill tailings located at active and inactive mill operations may pose a potential and significant radiation health hazard to the public, and that..."
- "Every reasonable effort should be made to provide for the stabilization, disposal, and control in a safe and environmentally sound manner of such tailings in order to prevent or minimize radon diffusion into the environment and to prevent or minimize other environmental hazards..."

To these ends, the Act required the EPA to set generally applicable standards to protect the public against both radiological and nonradiological hazards posed by residual radioactive materials at uranium mill tailings sites. Residual radioactive material means (1) tailings waste resulting from the valuable constituents, and (2) other wastes, including unprocessed ores or low-grade materials at sites related to uranium ore processing. The term "tailings" is used to refer to all of these wastes.

UMTRCA divided uranium mill tailings sites into two groups: Title I covering inactive and abandoned sites, and Title II covering those sites for which licenses had been issued by the Nuclear Regulatory Commission (NRC), by its predecessor or by an Agreement State. Twenty-four sites have been designated Title I sites under UMTRCA. Under the Act, the EPA developed generally applicable standards governing the remedial activities of the Secretary of Energy or his designee under Section 275a of the Atomic Energy Act of 1954 for those sites identified under Title I. The Department of Energy (DOE) is responsible for the cleanup and long-term stabilization of the tailings at these sites, consistent with the generally applicable standards developed by the EPA.

Under UMTRCA, the EPA was required to promulgate standards before the DOE could begin cleanup of the Title I sites. These standards required, to the maximum extent practicable, that these operations be consistent with the requirements of the Solid Waste Disposal Act (SWDA), as amended. The SWDA includes the provisions of the Resource Conservation and Recovery Act (RCRA).

Because some buildings had been found to be contaminated with tailings resulting in high radiation levels, interim standards for buildings were published in the *Federal Register* on April 22, 1980. This allowed the DOE to proceed with the cleanup of off-site tailings contamination without waiting for the formal promulgation of a regulation through the EPA rulemaking process. During this time, proposed standards for the cleanup of the inactive mill tailings were published for comment.

The proposed cleanup standards were followed by proposed disposal standards, published in the *Federal Register* on January 9, 1981. The disposal standards apply to the tailings at the 24 designated sites and are designed to place them in a condition that would remain safe for a long time. The final UMTRCA standards for the disposal and cleanup of inactive uranium mill tailings were issued on January 5, 1983.

The American Mining Congress and others immediately petitioned the Tenth Circuit Court of Appeals for a review of the standards. On September 3, 1985, the Tenth Circuit Court upheld the inactive mill tailings standards except for the ground-water protection portions, which were remanded to EPA for revision. The EPA is currently developing new standards under this rule. The disposal standard that applies to the 24 Title I sites (40 CFR 192, Subpart A) requires long-term stabilization of the tailings and establishes a design standard limiting the average radon-222 emission rate to 20 pCi/m^2/sec or less.

3.2 Inactive Industry Profile

3.2.1 Current Status of Inactive Mills

A typical site contains the mill buildings where ore was processed to remove the uranium, ore storage areas, and a tailings pile covering approximately 50 acres. The tailings pile is usually made by depositing slurried sand wastes on flat ground to form a pond into which there is further deposition of slurried sand, finer grained wastes ("slimes"), and process water. The water has since evaporated or seeped into the ground, leaving a large pile of mostly sand-like material. Some inactive sites also contain dried up raffinate ponds, special ponds where contaminated process water was stored until it evaporated. Mill buildings, ore storage areas, and dried up raffinate ponds are usually heavily contaminated with radioactive material. The amount of tailings produced by a mill is about equal in both weight and volume to the ore processed, since the recovered uranium is only a small part of the ore.

3.2.2 Use of Inactive Mill Sites

Housing and other structures that remain from milling operations have been frequently put to use. Housing at Tuba City, Naturita, Slick Rock, Shiprock, and Mexican Hat is occupied. Buildings on mill sites at Gunnison, Naturita, Shiprock, Green River, and Mexican Hat are being used for warehousing, schools, and for other purposes. Further, buildings are still used for company activities at several sites. A sewage disposal site is operating at the former site in Salt Lake City. The pressure for use of sites in urban areas is likely to increase with time as a result of population growth. The status and current reclamation schedule for inactive uranium mill sites are presented in Table 3-1.

Table 3-1. Status and Planned Remedial Action at Inactive Uranium Mill Sites (a).

Site	Quantity of Tailings (1,000,000 tons)	Proposed Action	Schedule(b) Start	Finish
Monument Valley, AZ	1.2	Removal to Mexican Hat Site	FY90	FY91
Tuba City, AZ	0.8	Stabilization in place	UW(c)	FY90
Durango, CO	1.6	Removal to Bodo Canyon Site	UW	FY90
Grand Junction, CO	1.9	Removal to Cheney Site	UW	FY93
Gunnison, CO	0.5	Removal to Landfill Site	FY90	FY92
Maybell, CO	2.6	Stabilization in place	FY91	FY92
Naturita, CO	0.6	Removal to Dry Flats Site	FY91	FY92
New Rifle, CO	2.7	Removal to Estes Gulch Site	UW	FY92
Old Rifle, CO	0.4	Removal to Estes Gulch Site	UW	FY92
Slick Rock (NC)(d), CO	0.04	Removal to Slick Rock (UC)	-	DONE
Slick Rock (UC)(e), CO	0.35	Stabilization in place	-	DONE
Lowman, ID	0.09	Stabilization in place	FY92	FY92
Ambrosia Lake, NM	2.6	Stabilization in place	UW	FY90
Shiprock, NM	1.5	Stabilization in place	-	DONE
Belfield, ND	---	Removal to Bowman Site	FY92	FY93
Bowman, ND	---	Stabilization in place	FY92	FY93
Lakeview, OR	0.13	Removal	-	DONE
Canonsburg, PA	0.4	Stabilization in place	-	DONE
Falls City, TX	2.5	Stabilization in place	FY90	FY92
Green River, UT	0.12	Stabilization in place	UW	DONE
Mexican Hat, UT	2.2	Stabilization in place	UW	FY91
Salt Lake City, UT	1.7	Removal to S. Clive Site	-	DONE
Converse County, WY	0.19	Stabilization in place	UW	FY89
Riverton, WY	0.9	Removal to UMETCO's Gas Hills Licensed Site	UW	FY91

(a) DOE88

(b) The start and finish dates refer to construction activities to stabilize and cover the tailings. The finish dates do not include development and implimentation of the Surveillance and Monitoring Program or Certification that the remedial action is complete.

(c) UW = underway, i.e., remedial actions to stabilize the tailings have been initiated.

(d) North Continent pile

(e) Union Carbide pile

3.3 Current Emissions, Risks, and Control Methods[1]

All but one of the 24 processing sites designated under Title I of the UMTRCA are situated in the generally semi-arid to arid western United States. The site locations vary from isolated, sparsely populated, rural settings to populated, urban communities.

The tailings contain residual radioactive materials, including traces of unrecovered uranium and most of the daughter products, as well as various heavy metals and other elements, often at levels exceeding established standards. The DOE's Uranium Mill Tailings Remedial Action Program (UMTRAP) calls for the removal of tailings from sites in highly populated areas or where the long-term stabilization is threatened by flooding or could result in the contamination of groundwater. Under Public Law 95-604 the DOE is to complete disposal and stabilization by the end of fiscal year (FY) 1994.

To date, disposal at seven sites has been completed and tailings at all sites are scheduled to be covered by February 1993 (DOE88). As can be seen in Table 3-1, once the DOE planned actions are completed, there will be a total of 19 disposal sites. However, since the remedial action at the Converse County site calls for disposal under 40 feet of cover, there will be 18 sites where there is a potential for radon-222 emissions that could cause risks to public health.

Previous analyses have shown that the only effective means of controlling radon emissions from the tailings is to bury the tailings with an earthen cover thick enough to attenuate the radon flux from the tailings. The UMTRCA standards require that the cover be designed so that the average radon flux does not exceed 20 $pCi/m^2/sec$. The design flux from the covers approved by the DOE range from the UMTRCA limit of 20 $pCi/m^2/sec$ down to 0.5 $pCi/m^2/sec$.

At sites where remedial action is pending, no controls are currently in place to reduce radon emissions. Thin interim earthen covers have been used at some sites. These are intended primarily to control wind erosion of the tailings and may reduce the amount of radon released to the air. At sites where long-term stabilization under UMTRCA has been completed, thick earthen covers have been placed on the tailings. As discussed in detail in Volume 2 of this *Environmental Impact Statement* (Appendix B) earthen covers reduce the amount of radon released to the air by retaining the radon under the cover long enough for it to decay. It is assumed that these covers reduce the radon flux to the flux for which they were designed.

---

[1] The source for the following section on emissions, risks and control methods is Chapter 8, Volume 2 of the *Environmental Impact Statement* (EPA89).

3.3.1 Current Emissions and Estimated Risk Levels

The radon releases from the tailings at the 18 inactive sites that will remain once UMTRCA disposal is completed are assessed on a site-by-site basis. The following sections discuss how the radon release rates are developed and the sources of the meteorological and demographic data used in the assessment.

3.3.1.1 Development of the Radon Source Terms

Estimates for the radon source terms for the post-UMTRCA disposal sites are based on the DOE's estimated radon fluxes through the approved cover designs and the areas of the disposal sites. The DOE's design fluxes and the areas of the disposal sites are those reported in DOE88. For the alternative fluxes of 6 and 2 pCi/m^2/sec, the source terms are calculated using the lower of the design flux or the appropriate flux limit. The areas of the final disposal sites, the cover design flux rate, and the radon source terms calculated for each pile are presented in Table 3-2.

3.3.1.2 Demographic and Meteorological Data

To assess the exposures and risks that result from the release of radon-222, site-specific meteorological and demographic data have been used. Demographic data for the nearby (0-5 km) individuals are developed for each site by surveys conducted during site visits (PNL84). These demographic data have been updated by the DOE and SC&A for certain piles (see Appendix A of Vol II for details). The results of that survey are summarized in Table 3-3. Data for the populations

Table 3-2. Summary of Radon-222 Emissions from Inactive Uranium Mill Tailings Disposal Sites.(a)

State/Site	Area of Site (acres)	Cover Design Flux (pCi/m2/s)	Radon-222 Releases (Ci/y)		
			Design Flux	6 pCi/m2/s Limit	2 pCi/m2/s Limit
Arizona					
Tuba City	22	9.3	2.6E+01	1.7E+01	5.6E+00
Colorado					
Durango -Bodo Canyon	40	20.0	1.0E+02	3.1E+01	1.0E+01
Grand Junction - Cheney Site	62	6.5	5.1E+01	4.8E+01	1.6E+01
Gunnison - Landfill Site	38	1.9	9.2E+00	9.2E+00	9.2E+00
Maybell	80	7.1	7.3E+01	6.1E+01	2.0E+01
Naturita - Mill Site	23	5(b)	1.5E+01	1.5E+01	5.9E+00
New/Old Rifle - Estes Gulch	71	20.0	1.8E+02	5.4E+01	1.8E+01
Slick Rock - Combined	6	5.8	4.4E+00	4.4E+00	1.5E+00
Idaho					
Lowman	5	5.7	3.6E+00	3.6E+00	1.3E+00
New Mexico					
Ambrosia Lake	105	16.7	2.2E+02	8.0E+01	2.7E+01
Shiprock	72	20.0	1.8E+02	5.5E+01	1.8E+01
North Dakota					
Bowman/Belfield	12	3.9	6.0E+00	6.0E+00	3.1E+00
Oregon					
Lakeview	30	7.5	2.9E+01	2.3E+01	7.7E+00
Pennsylvania					
Canonsburg	18	7.0	1.6E+01	1.4E+01	4.6E+00
Texas					
Falls City	146	13.2	2.5E+02	1.1E+02	3.7E+01
Utah					
Green River	9	0.5	5.7E-01	5.7E-01	5.7E-01
Mexican Hat	68	12.0	1.0E+02	5.2E+01	1.7E+01
Salt Lake City - S. Clive	50	20.0	1.3E+02	3.9E+01	1.3E+01
Totals	857		1.3E+03	5.9E+02	2.2E+02

(a) Emmissions are calculated based on the area of the site and the lower of the given flux limit and the DOE approved design flux.

(b) Final cover design not available, design flux of 5 pCi/m2/sec assumed due to the fact that only residual contamination exists at this site.

between 5-80 km are generated using the computer code SECPOP. Meteorological data are obtained from the nearest station with suitable joint frequency arrays. Details of the inputs that were provided to the AIRDOS/DARTAB/RADRISK codes are presented in Appendix A of Volume 2 of the *Environmental Impact Statement.*

3.3.1.3 Exposures and Risks to Nearby Individuals

The AIRDOS-EPA and DARTAB model codes are used to estimate the increased chance of lung cancer for individuals living near a tailings impoundment and receiving the maximum exposure. Estimates for the exposure and risk to nearby individuals once UMTRCA disposal is completed, as well as under alternative flux rates of 6 and 2 pCi/m^2/sec are shown in Table 3-4. The lifetime fatal cancer risks for individuals residing near inactive disposal sites range from 4E-7 to 2E-4. The maximum lifetime fatal cancer risk of about 2E-4 is estimated at the Shiprock site in New Mexico at a distance of 750 meters from the impoundment center.

3.3.1.4 Exposures and Risks to the Regional Population

Collective population risks, in deaths per year, for the region around the mill site are calculated from the annual exposure in person-WLM (working level months) for the population in the assessment area. Collective exposure calculations expressed in person-WLM are performed for each mill by multiplying the estimated concentration in each annular sector by the population in that sector. The estimated regional fatal cancers per year in the regional populations are presented for the DOE approved design flux and for alternative fluxes of 6 and 2 pCi/m^2/sec in Table 3-5.

3.3.1.5 Exposures and Risks Under Alternative Standards

Once the tailings piles are stabilized and disposed of at the DOE cover design flux, the radon-222 emission rates will all be at or below the UMTRCA design limit of 20 pCi/m^2/sec. As mentioned above, alternative flux limits of 6 and 2 pCi/m^2/sec are also evaluated. The exposures and risks under each of the alternative standards are presented in Tables 3-4 and 3-5, respectively. These estimates show that the maximum lifetime fatal cancer risk could be reduced from 2E-4 at the DOE design flux to 7E-5 at a limit of 6 pCi/m^2/sec, and to 2E-5 at a limit of 2 pCi/m^2/sec. The number of deaths per year that will occur in the regional population would be reduced by about one-half

Table 3-3. Estimated Number of Persons Living Within 5 km of the Centroid of Tailings Disposal Sites for Inactive Mills(a).

State/Site	Distance (kilometers) 0-0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	Total
Arizona							
Tuba City	0	18	12	15	0	19	64
Colorado							
Durango	0	0	2	0	0	0	2
Grand Junction	0	0	0	0	26	31	57
Gunnison	0	0	0	8	11	22	41
Maybell	0	0	0	0	0	0	0
Naturita	0	0	65	20	106	902	1,093
New/Old Rifle	0	0	0	16	0	49	65
Slick Rock	3	16	0	3	0	0	22
Idaho							
Lowman	9	76	87	0	16	30	218
New Mexico							
Ambrosia Lake	0	0	0	0	0	0	0
Shiprock	0	155	1,904	1,034	1,016	839	4,948
North Dakota							
Bowman/Belfield	0	3	9	3	6	12	33
Oregon							
Lakeview	0	16	543	1,704	1,457	464	4,184
Pennsylvania							
Canonsburg	950	2,960	7,988	5,126	2,830	281	22,135
Texas							
Falls City	0	3	18	0	15	9	45
Utah							
Green River	0	14	257	810	397	20	1,498
Mexican Hat	0	0	279	56	0	0	335
Salt Lake City	0	0	0	0	0	0	0
Total	962	3,261	11,164	8,795	5,880	4,678	34,740

(a) PNL84, updated per SC&A site visits and DOE data (see Vol. 2, Appendix A).

Table 3-4. Estimated Exposures and Risks to Nearby Populations Assuming Alternative Flux Rates.

State/Site	Distance (a) (meters)	DOE Design Flux			6 pCi/m2/s Limit			2 pCi/m2/s Limit		
		Maximum Radon Concentration (pCi/l)	Maximum Exposure (WL)	Maximum Lifetime Fatal Cancer Risk To Individual	Maximum Radon Concentration (pCi/l)	Maximum Exposure (WL)	Maximum Lifetime Fatal Cancer Risk To Individual	Maximum Radon Concentration (pCi/l)	Maximum Exposure (WL)	Maximum Lifetime Fatal Cancer Risk To Individual
Arizona										
Tuba City	1,500	2.0E-03	6.7E-06	9.0E-06	1.3E-03	4.4E-06	6.0E-06	4.4E-04	1.4E-06	2.0E-06
Colorado										
Durango	1,500	1.1E-02	3.7E-05	5.0E-05	3.3E-03	1.1E-05	2.0E-05	1.1E-03	3.7E-06	5.0E-06
Grand Junction	4,500	1.3E-03	5.7E-06	8.0E-06	1.3E-03	5.4E-06	7.0E-06	4.2E-02	1.8E-06	2.0E-06
Gunnison	4,500	1.6E-04	7.0E+07	1.0E-06	1.6E-04	7.0E-07	1.0E-06	1.6E-04	7.0E-07	1.0E-06
Maybell	15,000	8.9E-04	5.8E-06	8.0E-06	7.4E-04	4.8E-06	7.0E-06	2.4E-04	1.6E-06	2.0E-06
Naturita	250	1.3E-02	3.5E-05	5.0E-05	1.3E-02	3.5E-05	5.0E-05	5.0E-03	1.4E-05	2.0E-05
New/Old Rifle	2,500	2.7E-03	9.8E-06	1.0E-05	8.0E-04	2.9E-06	4.0E-06	2.7E-04	9.8E-07	1.0E-06
Slick Rock	250	3.6E-03	1.0E+05	1.0E-05	3.6E-03	1.0E-05	1.0E-05	1.2E-03	3.4E-06	5.0E-06
Idaho										
Lowman	250	4.4E-03	1.2E-05	2.0E-05	4.4E-03	1.2E-05	2.0E-05	1.9E-03	5.4E-06	6.0E-06
New Mexico										
Ambrosia Lake	7,500	3.7E-04	1.9E-06	3.0E-06	1.4E-04	6.9E-07	9.0E-07	4.6E-05	2.3E-07	3.0E-07
Shiprock	750	5.2E-02	1.6E+04	2.0E-04	1.6E-02	4.8E-05	7.0E-05	5.2E-03	1.6E-05	2.0E-05
North Dakota										
Bowman/Belfield	750	7.5E-04	2.2E-06	3.0E-06	7.5E-04	2.2E-06	3.0E-06	3.6E-04	1.2E-06	2.0E-06
Oregon										
Lakeview	2,500	1.9E-03	6.8E-06	9.0E-06	1.5E-03	5.4E-06	7.0E-06	4.9E-04	1.8E-06	2.0E-06
Pennsylvania										
Canonsburg	250	2.0E-02	5.4E-05	8.0E-05	1.7E-02	4.7E-05	7.0E-05	5.6E-03	1.6E-05	2.0E-05
Texas										
Falls City	1,500	1.4E-02	4.5E-05	6.0E-05	6.0E-03	2.0E-05	3.0E-05	2.0E-03	6.6E-06	9.0E-06
Utah										
Green River	750	2.1E-04	6.2E-07	9.0E-07	2.1E-04	6.2E-07	9.0E-07	2.1E-04	6.2E-07	9.0E-07
Mexican Hat	750	1.4E-02	4.1E-05	6.0E-05	5.6E-03	1.9E-05	3.0E-05	1.8E-03	6.1E-06	8.0E-06
Salt Lake City	15,000	4.2E-05	2.7E-07	4.0E-07	1.3E-05	8.2E-08	1.0E-07	4.2E-06	2.7E-08	4.0E-08

(a) Distance from center of a homogenous circular equivalent impoundment to the point where the exposures and risks were estimated.

Table 3-5. Estimated Fatal Cancers per Year in the Regional (0-80 km) Populations Around Inactive Tailings Disposal Sites Assuming Alternative Radon Flux Rates (a).

	Design flux	6 pCi/m2/s	2 pCi/m2/s
State/Site	Fatal Cancers per Year	Fatal Cancers per Year	Fatal Cancers per Year
Arizona			
Tuba City	1.3E-04	8.8E-05	2.9E-05
Colorado			
Durango	6.7E-04	2.1E-04	6.7E-05
Grand Junction	9.9E-04	9.3E-04	3.1E-04
Gunnison	7.5E-05	7.5E-05	7.5E-05
Maybell	1.0E-04	8.5E-05	2.8E-05
Naturita	3.5E-05	3.5E-05	1.4E-05
New/Old Rifle	5.3E-04	1.6E-04	5.3E-05
Slick Rock	6.4E-06	6.4E-06	2.2E-06
Idaho			
Lowman	9.7E-06	9.7E-06	3.6E-06
New Mexico			
Ambrosia Lake	5.3E-04	1.9E-04	6.5E-05
Shiprock	3.0E-03	9.2E-04	3.0E-04
North Dakota			
Bowman/Belfield	4.0E-06	4.0E-06	2.1E-06
Oregon			
Lakeview	1.3E-04	1.1E-04	3.6E-05
Pennsylvania			
Canonsburg	4.7E-03	4.1E-03	1.4E-03
Texas			
Falls City	7.1E-03	3.1E-03	1.1E-03
Utah			
Green River	3.3E-06	3.3E-06	3.3E-06
Mexican Hat	3.4E-04	1.7E-04	5.7E-05
Salt Lake City	4.9E-05	1.5E-05	4.9E-06
Totals	1.8E-02	1.0E-02	3.5E-03

(a) Fatal cancers per year are calculated based on the lower of the given flux limit and the DOE design flux.

(from 2E-2 to 1E-2) at a limit of 6 pCi/m^2/sec. At a limit of 2 pCi/m^2/sec, the deaths per year would be reduced by about nine-tenths (from 2E-2 to 3E-3).

3.3.1.6 Distribution of the Fatal Cancer Risk

The frequency distribution of the estimated lifetime fatal cancer risk for all inactive uranium mill tailings piles for each alternative are presented in Table 3-6. This distribution is developed by simply summing the frequency distributions projected for each of the 18 facilities. The distribution does not account for overlap in the populations exposed to radon-222 released from more than a single mill. Given the remote locations of these facilities and the relatively large distances between mills, this simplification does not significantly understate the lifetime fatal cancer risk to any individual.

3.3.2 Control Technologies

Previous studies have examined the feasibility, effectiveness, and cost associated with various options for controlling releases of radioactive materials from uranium mill tailings (NRC80, EPA82, EPA83, EPA86). These studies have concluded that long-term stabilization and control will be required to protect the public from the hazards associated with these tailings. The standards for long-term disposal, established for these Title I sites under UMTRCA, provide for controls to prevent misuse of the tailings, protect water resources, and limit releases of radon-222 to the air. The UMTRCA standard established a design standard to limit long-term radon releases to an average flux no greater than 20 pCi/m^2/sec.

Both active and passive controls are available to reduce radon-222 emissions from tailings. Active controls require that some institution, usually a government agency, take the responsibility for continuing oversight of the piles, and for making repairs to the control system when needed. Fences, warning signs, periodic inspections and repair, and restrictions on land use are measures that may be used by the oversight agency. Passive controls are measures of sufficient permanence to require little or no active intervention. Passive controls include measures such as thick earth or rock covers, barriers (dikes) to protect against floods, burial below grade, and moving piles out of flood prone areas or away from population centers. Of the two methods, active or institutional controls are not preferred for long-term stabilization of radon-222 emissions, since institutional performance of oversight duties over a substantial period of time may not be reliable.

Table 3-6. Estimated Distribution of Fatal Cancer Risk to the Regional (0-80 km) Populations from Inactive Uranium Mill Tailings Disposal Sites Assuming Alternative Flux Rates.

	DOE Design Flux		6 pCi/m2/s		2 pCi/m2/s	
Risk Interval	Number of Persons	Deaths Per Yr	Number of Persons	Deaths Per Yr	Number of Persons	Deaths Per Yr
1E-1 to 1E+0	0	0	0	0	0	0
1E-2 to 1E-1	0	0	0	0	0	0
1E-3 to 1E-2	0	0	0	0	0	0
1E-4 to 1E-3	130(a)	4.0E-04	0	0	0	0
1E-5 to 1E-4	4,500	2.0E-03	2,500	1E-3	1,100	2E-4
1E-6 to 1E-5	89,000	2.0E-03	28,000	1E-3	7,500	3E-4
< 1E-6	4,900,000	1.0E-02	5,000,000	8E-2	5,000,000	3E-3
Totals*	5,000,000	2E-2	5,000,000	1E-2	5,000,000	3E-3

(a) All individuals in this risk interval reside near the Shiprock disposal site in New Mexico.

* Totals may not add due to independent rounding.

Previous studies (see above) have identified a number of options to provide long-term control of radon-222 emissions from the tailings. These include earthen or synthetic covers, extraction of radium from the tailings, chemical fixation, and sintering. These long-term control options are discussed in detail in Volume 2 of this *Environmental Impact Statement (Appendix B).*

In comparison to other control technologies earth covers have been shown to be cost-effective (NRC80). Apart from cost considerations, there are other benefits that accrue by using earth covers as a method to control radon-222 emissions. For example, synthetic covers, such as plastic sheets, do not reduce gamma radiation. However, earth covers that are thick enough to reduce radon-222 emissions will reduce gamma radiation to insignificant levels. Further, chemical and physical stresses over a substantial period of time destabilize synthetic covers, while earthen covers are stable over the long run provided the erosion caused by rain and wind is contained with vegetation or rock covers, and appropriate precautions are taken against natural catastrophes.

Earthen covers also reduce the contamination of groundwater that results from two alternative control methods: storing radioactive materials in underground mines (underground mines are typically located under the water table), or using the leaching process to extract radioactive and non-radioactive contaminants from mill tailings. Moreover, although underground mine disposal is an effective method to protect against degradation and intrusion by man, it nevertheless incurs a social cost. For example, storing tailings in underground mines eliminates the future development of the mines' residual resources.

Finally, earthen covers provide more effective long-term stabilization than either water or soil cement covers. Soil cement covers are comparable to earthen covers in terms of cost-effectiveness, but the long-term performance of these is as yet unknown. Water covers do not provide the long-term stability required for the 1000-year time periods required. Moreover, earth covers are more effective stabilizers in arid regions than are water spraying control technologies.

Covering the dried tailings with earth is an effective method for reducing radon-222 emissions and is already in use at inactive tailings impoundments. The depth of soil required for a given amount of control varies with the type of earth and radon-222 exhalation rate.

Earth covers decrease radon-222 emissions by the retaining radon-222 released from the tailings long enough to allow a significant portion to decay in the cover. A rapid decrease in radon-222 emissions is immediately achieved by applying almost any type of earth. High-moisture content earths provide greater radon-222 emission reduction because of their smaller diffusion coefficient.

In practice, earthen cover designs must take into account uncertainties in the measured values of the specific cover materials used, the tailings to be covered, and predicted long-term values of equilibrium moisture content for the specific location. The uncertainty in predicting reductions in radon-222 flux increases rapidly as the required radon-222 emission limit is lowered.

The cost of adding earth covers depends on the location of the tailings impoundment, its layout, the availability of earth, the topography of the disposal site, its surroundings, and the hauling distance. Another factor affecting costs of cover material is its ease of excavation. In general, the more difficult the excavation, the more elaborate and expensive the equipment required and the higher the cost. The availability of materials, such as gravel, dirt, and clay, also affects costs. If the necessary materials are not available locally, they must be purchased and/or hauled, and costs could increase significantly as a result.

3.4 Analysis of Benefits and Costs

This section presents the benefits and costs of reducing the allowable radon emissions after closure from the maximum limit of 20 $pCi/m^2/sec$ established under UMTRCA. Options which are evaluated include lowering radon emissions to a maximum of 6 $pCi/m^2/sec$ or a maximum of 2 $pCi/m^2/sec$.

This analysis assumes that UMTRCA is in place and that all controls required under UMTRCA will be met regardless of any provisions resulting from this reconsideration of the CAA standards. Therefore, the beginning point of this analysis (i.e., the baseline) assumes that all controls required by UMTRCA are met, specifically that radon emission levels will be limited to a maximum of 20 $pCi/m^2/sec$ and that measures will be undertaken to achieve the long-run stability required by the UMTRCA rules.

Benefits are measured as reductions in the estimates of committed fatal cancers resulting from lower allowable emissions. Results are presented in terms of both total benefits and average annual benefits. For the calculation of total benefits a 100-year time period is assumed.

All costs are measured in 1988 dollars and represent the cost of both the disposal and stabilization of the tailings. Cost estimates are calculated assuming no remedial actions have taken place. The costs of meeting the DOE design flux, the 6 pCi/m^2/sec and the 2 pCi/m^2/sec are then estimated. The cost of the alternative standards are the incremental costs from the baseline (DOE design flux) to the 6 or 2 pCi/m^2/sec alternative. Results are presented in net present value and annualized cost, and are estimated using real interest rates of zero, one percent, five percent and ten percent. A 100-year time period is used.

3.4.1 Benefits

It is assumed that reductions in the radon flux rate provided by increasing the depth of cover will yield proportional reductions in committed cancers. The resulting estimates of committed cancers per year on a pile-by-pile basis are presented above for the DOE cover design flux, 6 and 2 pCi/m^2/sec options in Table 3-5.

Table 3-7 summarizes the estimates of risk and reduction of risk (committed cancers) for the various regulatory options. The table presents these estimates for the 100-year period as well as annual averages. Over the 100-year time frame, the 6 pCi/m^2/sec option lowers regional risks by 0.8 committed cancers. The incremental benefit of lowering the allowable flux rate from 6 pCi/m^2/sec to 2 pCi/m^2/sec is estimated as 0.65 committed cancers.

3.4.2 Costs

For reasons described in Section 3.3.2, the supplemental control selected for long-term radon-222 control at inactive tailings impoundments is the earthen cover control option. The thickness of cover required to achieve a given radon flux is a function of the initial radon flux from the pile. Five operations are required to place earthen covers on inactive tailings piles. These include: regrading slopes, procurement and placing of the dirt cover, placing gravel on the pile tops, placing of rip-rap on the pile sides, and reclamation of the borrow pits. The estimation of earth cover thicknesses and the costs for the five operations are described in detail in Appendix B of Volume 2 of the *Environmental Impact Statement*.

Three overhead cost factors were used to adjust the cost of earth cover described above. First, a factor of 1.07 was applied to reflect general industry overhead and costs, (for a discussion of cost factors see Appendix B, Volume 2). Second, a project cost factor of 3.4, based upon UMTRAP experience, was applied to reflect additional government costs for community participation,

Table 3-7: Total and Annualized Risk and Reduction of Risk (Committed Cancers) of Lowering the Allowable Flux limit to 6 and 2 pCi/m2/sec.

	20 pdCi/m2/sec Baseline	6 pCi/m2/sec Option		2 pCi/m2/sec Option		
	Risk	Risk	Risk Reduction from 20 pCi/m2/sec Baseline	Risk	Risk Reduction from 20 pCi/m2/sec Baseline	Risk Reduction from 6 pCi/m2/sec Baseline
Risk	1.8	1.00		0.35		
Cancers avoided over 100 years:			0.80		1.45	0.65
Risk	0.0180	0.0100		0.0035		
Annual cancers avoided:			0.0080		0.0145	0.0065

technology development and evaluation, site acquisition, costs for a planning contractor, management support, design, construction management, and associated services. Finally, since many of these items represent sunk costs, an alternative factor of 2.4, which measures only estimated future costs, is also included in the analysis.

The estimates of costs on a pile-by-pile basis are presented for the DOE design flux, 6 and 2 pCi/m^2/sec options in Tables 3-8, 3-9, and 3-10, respectively. Achieving the DOE design flux is estimated to cost between \$136 and \$418 million. In contrast, reaching the 6 pCi/m^2/sec option is estimated to cost from \$157 to \$483 million, while compliance with the 2 pCi/m^2/sec option would entail costs estimated to reach between \$188 and \$579 million.

Expenditures to meet the DOE design flux or the 6 and 2 pCi/m^2/sec options are assumed to begin in 1989 and be accomplished over five years. Dollar expenditures are in equal amounts in each of the five years in current dollars.

Table 3-11 provides the incremental present value costs for the three radon fluxes and added costs for lowering the allowable flux. Estimates for each of the DOE project cost factors and each of the four real interest rates, are included. Lowering the allowable flux rate to 6 pCi/m^2/sec will entail added present value costs of between \$13 and \$64 million depending on assumptions as to project cost and discount rates, while attainment of a 2 pCi/m^2/sec flux rate would entail costs of \$33 to \$161 million. The incremental costs of moving from the 6 pCi/m2/sec option to the 2 pCi/m2/sec option is estimated to range from \$19 to \$96 million.

The present value costs are also shown graphically in Figure 3-1. This graph indicates that the marginal cost per unit of radon flux reduction is lower between 20 pCi/m^2/sec and 6 pCi/m^2/sec than between 6 pCi/m^2/sec and 2 pCi/m^2/sec. This reflects the increasing depth of cover required per unit decrease in radon flux. Figure 3-1 also shows that the cost per unit of radon flux reduction is lower at higher real interest rates reflecting the reduced present value of future cash streams.

Table 3-12 provides similar estimates to those given in Table 3-11, except the values in 3-12 are presented on an annualized cost basis. For the 6 pCi/m^2/sec option, added costs on an annualized basis range from \$1.1 to \$4.8 million depending on cost factor and discount rate assumptions. For the 2 pCi/m^2/sec option, added costs vary from \$2.6 to \$11.8 million.

Table 3-8: Costs of Achieving the DOE Approved Cover Design Flux for Inactive Mill Tailings.
(1988 $, Million).

Pile Name	Regrade Slopes	Dirt Cover	Apply Riprap	Apply Gravel	Reclaim Borrow Pits	Total	Total Incl. Cost Factor @ 1.07	Total Incl. Cost Factor @ 2.4	Total Incl. Cost Factor @ 3.3
Tuba City	0.09	3.07	0.41	0.20	0.15	3.93	4.20	9.42	12.96
Durango	0.23	4.81	0.75	0.37	0.23	6.39	6.84	15.34	21.09
Grand Junction	0.44	9.82	1.16	0.57	0.48	12.47	13.35	29.94	41.16
Gunnison	0.21	6.65	0.71	0.35	0.32	8.25	8.83	19.81	27.23
Maybell	0.65	9.14	1.50	0.74	0.45	12.48	13.35	29.94	41.17
Naturita	0.10	1.77	0.44	0.22	0.09	2.61	2.80	6.27	8.62
Rifle	0.54	8.77	1.33	0.66	0.43	11.73	12.55	28.15	38.70
Slick Rock	0.01	0.61	0.11	0.06	0.03	0.82	0.88	1.98	2.72
Lowman	0.01	0.57	0.09	0.05	0.03	0.75	0.80	1.79	2.46
Ambrosia Lake	0.98	12.68	1.97	0.97	0.62	17.21	18.42	41.31	56.80
Shiprock	0.55	7.49	1.35	0.67	0.37	10.42	11.15	25.00	34.38
Bowman/Belfield	0.04	1.05	0.22	0.11	0.05	1.47	1.58	3.53	4.86
Lakeview	0.15	2.75	0.56	0.28	0.13	3.86	4.14	9.28	12.75
Canonsburg	0.07	3.57	0.34	0.17	0.17	4.32	4.62	10.36	14.24
Falls City	1.60	13.32	2.74	1.35	0.65	19.66	21.03	47.17	64.86
Green River	0.02	1.54	0.17	0.08	0.08	1.89	2.02	4.54	6.25
Mexican Hat	0.02	0.93	0.13	0.06	0.05	1.19	1.27	2.85	3.92
Salt Lake	0.32	5.40	0.93	0.46	0.26	7.37	7.88	17.68	24.32
Totals	6.05	93.92	14.91	7.36	4.58	126.81	135.69	304.35	418.49

Table 3-9: Costs of Achieving the 6 pCi/m2/sec Flux Limit.
(1988 $, Million).

Pile Name	Regrade Slopes	Dirt Cover	Apply Riprap	Apply Gravel	Reclaim Borrow Pits	Total	Total Incl. Cost Factor @ 1.07	Total Incl. Cost Factor @ 2.4	Total Incl. Cost Factor @ 3.3
Tuba City	0.09	3.40	0.41	0.20	0.17	4.27	4.57	10.25	14.10
Durango	0.23	6.46	0.75	0.37	0.31	8.12	8.69	19.49	26.80
Grand Junction	0.44	9.99	1.16	0.57	0.49	12.65	13.54	30.36	41.75
Gunnison	0.21	6.65	0.71	0.35	0.32	8.25	8.83	19.81	27.23
Maybell	0.65	9.60	1.50	0.74	0.47	12.96	13.87	31.10	42.76
Naturita	0.10	1.77	0.44	0.22	0.09	2.61	2.80	6.27	8.62
Rifle	0.54	11.69	1.33	0.66	0.57	14.79	15.83	35.50	48.81
Slick Rock	0.01	0.61	0.11	0.06	0.03	0.82	0.88	1.98	2.72
Lowman	0.01	0.57	0.09	0.05	0.03	0.75	0.80	1.79	2.46
Ambrosia Lake	0.98	16.35	1.97	0.97	0.80	21.07	22.54	50.56	69.52
Shiprock	0.55	10.45	1.35	0.67	0.51	13.52	14.47	32.45	44.62
Bowman/Belfield	0.04	1.05	0.22	0.11	0.05	1.47	1.58	3.53	4.86
Lakeview	0.15	2.97	0.56	0.28	0.15	4.10	4.39	9.85	13.54
Canonsburg	0.07	3.66	0.34	0.17	0.18	4.41	4.72	10.60	14.57
Falls City	1.60	17.26	2.74	1.35	0.84	23.78	25.45	57.08	78.49
Green River	0.02	1.54	0.17	0.08	0.08	1.89	2.02	4.54	6.25
Mexican Hat	0.02	1.10	0.13	0.06	0.05	1.36	1.45	3.25	4.47
Salt Lake	0.32	7.44	0.93	0.46	0.36	9.51	10.18	22.83	31.39
Totals	6.05	112.55	14.91	7.36	5.49	146.35	156.60	351.25	482.97

Note: Costs calculated for the lower of 6 pCi/m2/sec or the DOE design flux.

Table 3-10: Costs of Achieving the 2 pCi/m2/sec Flux Limit.
(1988 $, Million).

Pile Name	Regrade Slopes	Dirt Cover	Apply Riprap	Apply Gravel	Reclaim Borrow Pits	Total	Total Incl. Cost Factor @ 1.07	Total Incl. Cost Factor @ 2.4	Total Incl. Cost Factor @ 3.3
Tuba City	0.09	4.22	0.41	0.20	0.21	5.14	5.50	12.33	16.96
Durango	0.23	7.96	0.75	0.37	0.39	9.70	10.38	23.27	32.00
Grand Junction	0.44	12.32	1.16	0.57	0.60	15.09	16.15	36.23	49.81
Gunnison	0.21	6.65	0.71	0.35	0.32	8.25	8.83	19.81	27.23
Maybell	0.65	12.61	1.50	0.74	0.61	16.11	17.24	38.67	53.17
Naturita	0.10	2.50	0.44	0.22	0.12	3.38	3.62	8.12	11.17
Rifle	0.54	14.36	1.33	0.66	0.70	17.58	18.81	42.20	58.03
Slick Rock	0.01	0.83	0.11	0.06	0.04	1.05	1.13	2.53	3.48
Lowman	0.01	0.75	0.09	0.05	0.04	0.93	1.00	2.24	3.08
Ambrosia Lake	0.98	20.30	1.97	0.97	0.99	25.20	26.97	60.49	83.18
Shiprock	0.55	13.15	1.35	0.67	0.64	16.35	17.50	39.25	53.97
Bowman/Belfield	0.04	1.32	0.22	0.11	0.06	1.76	1.88	4.22	5.81
Lakeview	0.15	4.10	0.56	0.28	0.20	5.28	5.65	12.68	17.43
Canonsburg	0.07	4.34	0.34	0.17	0.21	5.12	5.48	12.30	16.91
Falls City	1.60	22.74	2.74	1.35	1.11	29.54	31.61	70.89	97.48
Green River	0.02	1.54	0.17	0.08	0.08	1.89	2.02	4.54	6.25
Mexican Hat	0.02	1.35	0.13	0.06	0.07	1.62	1.74	3.90	5.36
Salt Lake	0.32	9.31	0.93	0.46	0.45	11.47	12.27	27.53	37.85
Totals	6.05	140.34	14.91	7.36	6.85	175.50	187.79	421.21	579.16

Note: Costs calculated for the lower of 2 pCi/m2/sec or the DOE design flux.

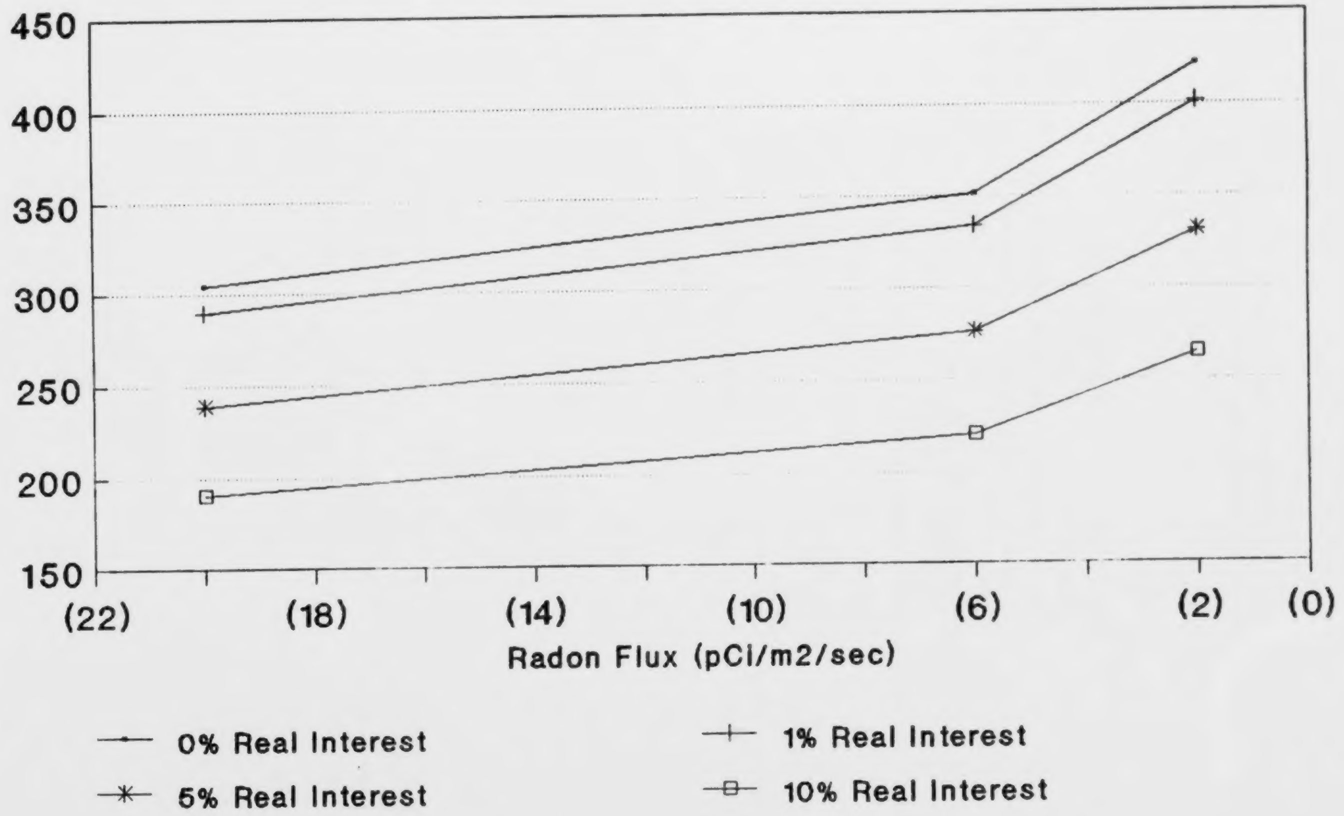
Table 3-11: Incremental Present Value Costs of Lowering the Allowable Limit to 6 pCi/m2/sec and 2 pCi/m2/sec for Inactive Piles. (1988 $, Millions)

	6 pCi/m2/sec Option	2 pCi/m2/sec Option	
	Incremental Cost From 20 pCi/m2/sec Baseline	Incremental Cost From 20 pCi/m2/sec Baseline	Incremental Cost From 6 pCi/m2/sec Option
1.07 Cost Factor			
0 % Real Interest Rate	$20.91	$52.10	$31.19
1 % Real Interest Rate	$19.90	$49.57	$29.68
5 % Real Interest Rate	$16.42	$40.92	$24.50
10 % Real Interest Rate	$13.10	$32.64	$19.54
1.4 DOE Cost Factor			
0 % Real Interest Rate	$46.90	$116.85	$69.96
1 % Real Interest Rate	$44.62	$111.19	$66.57
5 % Real Interest Rate	$36.83	$91.78	$54.94
10 % Real Interest Rate	$29.38	$73.22	$43.83
2.3 DOE Cost Factor			
0 % Real Interest Rate	$64.48	$160.67	$96.19
1 % Real Interest Rate	$61.36	$152.89	$91.53
5 % Real Interest Rate	$50.64	$126.19	$75.55
10 % Real Interest Rate	$40.40	$100.68	$60.27

Table 3-12: Incremental Annualized Costs of Lowering the Allowable Limit to 6 pCi/m2/sec and 2 pCi/m2/sec for Inactive Piles. (1988 $, Millions)

	6 pCi/m2/sec Option	2 pCi/m2/sec Option	
	Incremental Cost From 20 pCi/m2/sec Baseline	Incremental Cost From 20 pCi/m2/sec Baseline	Incremental Cost From 6 pCi/m2/sec Option
1.07 Cost Factor			
0 % Real Interest Rate	$1.05	$2.60	$1.56
1 % Real Interest Rate	$1.10	$2.75	$1.64
5 % Real Interest Rate	$1.32	$3.28	$1.97
10 % Real Interest Rate	$1.54	$3.83	$2.30
1.4 DOE Cost Factor			
0 % Real Interest Rate	$2.34	$5.84	$3.50
1 % Real Interest Rate	$2.47	$6.16	$3.69
5 % Real Interest Rate	$2.96	$7.36	$4.41
10 % Real Interest Rate	$3.45	$8.60	$5.15
2.3 DOE Cost Factor			
0 % Real Interest Rate	$3.22	$8.03	$4.81
1 % Real Interest Rate	$3.40	$8.47	$5.07
5 % Real Interest Rate	$4.06	$10.13	$6.06
10 % Real Interest Rate	$4.75	$11.83	$7.08

Figure 3-1.
Cost of Lowering the Allowable Flux



3.5 Economic Impact Analysis

The purpose of this section is to evaluate the economic impacts of Federal and state expenditures to comply with the costs associated with lowering the allowable radon-222 emission rate. No attempt is made to quantify these impacts, instead a qualitative discussion is given.

The costs of regulatory remedial actions, for any inactive mills not on Indian lands, are shared by the Federal and State governments. The Federal Government is accountable for ninety percent of these costs. In the case of Indian lands, however, the Federal Government is solely responsible for any costs associated with the disposal of tailings. Thus, these regulations have no impact on the uranium industry. In addition, there will be no impact on small businesses.

Any regulatory remedial action is expected to have positive economic impacts at both the state and local levels. The impacts are the result of fiscal injections and could be measured in terms of increased local employment, income and standards of living. These funds would come from the Federal (DOE) and State budgets. The expenditures are transfer payments, i.e., the funds are generated through taxes and spent on particular programs or areas. In most cases these expenditures will result in higher Federal expenditures within each state than would have occurred without these programs. There will be no disproportionate increase, however, in Federal taxes paid by residents of these states.

REFERENCES

DOE88 U.S. Department of Energy, "Annual Status Report on the Uranium Mill Tailings Remedial Action Program," Washington, D.C., December 1988.

EPA82 U.S. Environmental Protection Agency, *Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites* (40 CFR 192), Vol.I, EPA 520/4-82-013-1, Office of Radiation Programs, Washington, D.C., October 1982.

EPA83 U.S. Environmental Protection Agency, *Final Environmental Impact Statement for Standards for the Control of By-Product Materials from Uranium Ore Processing* (40 CFR 192), Vol, I, EPA 520/1-83-008-1, Office of Radiation Programs, Washington, D.C. 1983

EPA86 U.S. Environmental Protection Agency, *Final Rule for Radon-222 Emissions from Licensed Uranium Mill Tailings*, EPA 520/1-86-009, OFfice of RAdiation Programs, Washington, D.C., August 1986.

EPA89 *Risk Assessments*, Vol. 2.

NM 85 Personal communication, Energy and Minerals Department, Mine Inspection Bureau, State of New Mexico, December 1985.

NRC80 U.S. Nuclear Regulatory Commission, *Final Generic Environmental Impact Statement on Uranium Milling*, NUREG-0706, Washington, D.C., September 1980.

PNL84 Pacific Northwest Laboratory. "Estimated Population Near Uranium Tailings," PNL-4959, WC-70, Richland, WA, Janurary 1984.

CHAPTER 4

LICENSED URANIUM MILL TAILINGS FACILITIES

4. LICENSED MILL TAILINGS

4.1 Introduction and Summary

The licensed uranium mill tailings source category comprises the tailings impoundments and evaporation ponds created by conventional acid or alkaline leach processes at uranium mills licensed by the Nuclear Regulatory Commission (NRC) or the Agreement States. Recovery of uranium by conventional milling results in the release of uranium and its decay products to the air. The risks associated with the release of uranium and other radionuclides in the form of particulates are addressed in the proposed regulation for the uranium fuel cycle source category (Chapter 1). This assessment addresses only radon-222 released from the tailings impoundments and their associated evaporation ponds. Previous evaluations have shown that radon releases from other milling operations are insignificant [NRC80, EPA82, EPA83, EPA86].

In August 1988, the conventional uranium milling industry in the United States consisted of 26 licensed facilities. The licensed conventional uranium mills that have operated are in Colorado, New Mexico, South Dakota, Texas, Utah, Washington, and Wyoming. Only 4 of the 26 licensed facilities were operating; 8 were on standby status; and 14 were being or have been decommissioned. The mills on standby status are being maintained, but they are not processing uranium ore. When demand for uranium increases, these standby mills can resume milling. The decommissioned mills have been dismantled and have either been moved off-site or disposed of on-site. These mills can never resume operations. Their associated tailings impoundments are either being reclaimed, or plans to reclaim them have been made. Three other mills have been licensed, but two were never constructed, and one was built but never operated. These three mills are not discussed further here [EPA89].

The purpose of this chapter is to examine the costs, benefits, and economic impacts of three separate decisions that need to be addressed in promulgating the new Clean Air Act standards for release of radionuclides from licensed uranium mill tailings piles. The first decision to address is whether to reduce the limit on allowable radon-222 emissions after closure from the current Uranium Mill Tailings Radiation Control Act (UMTRCA) standard of 20 pCi/m^2/sec Options that are evaluated include allowable limits of 6 pCi/m^2/sec and 2 pCi/m^2/sec.

The second decision to consider is whether to reduce the limit on allowable emissions of operating mills without curtailing the operation of the mills. The limit to be considered is a maximum average radon emission of 20 $pCi/m^2/sec$ during the operational life of the facility.

While the first two decisions are focused on existing piles, the third is concerned with future tailings impoundments. The decision to be addressed for future tailings is whether work practice standards should be promulgated for the control of radon emissions from operating mills in the future. Options that are investigated include the replacement of the traditional single cell impoundment with phased or continuous disposal impoundments.

The remainder of this introduction provides a brief summary of the rulemaking history and current regulations. A profile of the uranium milling industry is given in Section 4.2. Included are industry characteristics such as demand and supply, financial and community analyses, and projections of industry production and employment. Section 4.3 addresses current emissions, risk levels and feasible control methods. Section 4.4 provides estimated benefits and costs for each of the options under the separate decision frameworks. The economic impacts are considered in Section 4.5.

4.1.1 Rulemaking History and Current Regulations

On January 13, 1977, the EPA issued Environmental Protection Standards for Nuclear Power Operations. These standards (40 CFR 190) limit the total individual radiation dose during normal operations from uranium fuel cycle facilities, including licensed uranium mills. However, when 40 CFR 190 was promulgated, considerable uncertainty existed regarding the public health risk from radon-222 and the best method for managing new manmade sources of this radionuclide. Therefore, the doses caused by emissions of radon-222 are excluded from the limits established in 40 CFR 190.

On April 6, 1983, the Agency proposed National Emission Standards for Hazardous Air Pollutants (NESHAPS) for radionuclides under Section 112 of the Clean Air Act (CAA). At that time, it determined that uranium fuel cycle facilities should be exempt from the NESHAP for NRC-Licensed Facilities, since they were already subject to the dose limits of 40 CFR 190. During the comment period, it was noted however, that radon-222 emissions from operating uranium mills posed significant public health risks and that such emissions were not subject to any current or proposed EPA standards.

On September 30, 1983, under the authority of UMTRCA, the Agency issued final standards (40 CFR 192) for the management of mill tailings at licensed facilities. Although the UMTRCA standard requires procedures to maintain radon-222 emissions as low as reasonably achievable (ALARA) during operations, it does not impose a numerical limit on radon-222 emissions until after closure of a facility. Current NRC regulations impose a concentration limit at the boundary. After closure, the tailings must be disposed of in accordance with the standard, and the post-disposal radon-222 emission rate cannot exceed an average of 20 $pCi/m^2/sec$. At the time the UMTRCA standard was promulgated, taking into account the comments received during the radionuclide NESHAPS rulemaking, the Agency stated that it would issue a Notice of Proposed Rulemaking (under Section 112 of the CAA) with respect to control of radon-222 emissions from uranium tailings piles during the operational period of a uranium mill. This notice was published on October 21, 1984.

On September 24, 1986, the Agency promulgated a NESHAP (40 CFR 61, Subpart W) for radon-222 emissions from licensed uranium mills during operations. NESHAP imposes a work practice standard of either phased or continuous disposal on all new tailings impoundments and prohibits the use of existing tailings piles after December 31, 1992.

4.2 Industry Profile

The U.S. uranium milling industry is an integral part of a domestic uranium production industry that includes companies engaged in uranium exploration, mining, milling, and downstream activities leading to the production of fuel for nuclear power plants. The product of uranium milling is uranium concentrate, also referred to as uranium oxide, yellowcake, or U_3O_8. Uranium concentrate may be produced either from mined and milled ore or through alternative sources such as solution mining, heap leaching, mine water, mill tailings, low-grade stockpiles, and as a byproduct of other activities. Only production from conventionally mined and milled ore is addressed in this chapter (see Section 4.2.2).

4.2.1 Demand

Domestic producers of uranium concentrate have two markets for their production: the U.S. nuclear power industry and exports. The nuclear power industry is the more important of the two. Military uses, once the only source of demand for uranium, have been supplied solely by government stockpiles since 1970 [DOE 87a].

Demand for domestic uranium has declined since the late 1970s. In 1979, utilities delivered 15,450 tons of domestic uranium oxide to DOE for enrichment, 86 percent more than 1986 deliveries. Exports, too, have declined substantially. In 1979, exports amounted to 3,100 tons, almost four times as much as in 1986. A number of negative forces have combined to cause the current depressed state of the industry. Perhaps most importantly, the growth in electricity generated by nuclear plants and the expansion of nuclear power capacity has been much slower than had been forecast in the mid-1970s. This slower growth is due in part to numerous construction delays and cancellations. Second, imports have begun to play a major role in the U.S. uranium market. The import restrictions were gradually withdrawn between 1975 and 1985. The result has been a steady increase in uranium imports from nations possessing high grade (and thus low cost) uranium deposits. Expectations are that a growing portion of utility requirements will be supplied by foreign-origin uranium during the second half of this decade [JFA 85a].

Also contributing to the current downturn in the uranium industry are the large inventories being held by both producers and utilities. Utilities, anticipating a growing need for uranium, entered into long-term contracts to purchase large amounts of domestically-produced uranium. As actual needs fell short of expected needs due to nuclear power plant construction delays and cancellations, large inventories accumulated. These inventory supplies, currently estimated to cover four to five years of utility requirements, adversely affect suppliers in two ways. They may extend the downturn in uranium demand for a number of years by decreasing the need for utilities to enter into new contracts. Also, high interest rates increased inventory holding costs, leading some utilities to contribute to current excess supply by offering inventory stocks for sale on the spot market [JFA 85a].

The focus of the remainder of this section is total U.S. demand for uranium, not just demand for domestic production or production from conventional mills. The first subsection details historical uses of uranium. The concluding subsection provides a brief description of uranium prices and pricing mechanisms.

4.2.1.1 Uranium Uses

Military Applications

In the early 1950s, the U.S. government's need for uranium for defense uses far exceeded the world's production capability. A federally funded production incentives program was then instituted. The incentives program was so effective that the government phased it out in the 1960s and terminated its purchase program in 1970. The government still has sufficient stockpiles to meet military requirements well into the future.

Nuclear Power Plants

Since 1971, utilities which use uranium as fuel for nuclear power plants, have been virtually the only source of demand for current uranium production. Commercial generation of nuclear powered electricity began in 1957 with the operation of the first central station reactor at Shippingport, Pennsylvania. At the end of 1986, 100 nuclear reactors were licensed to operate in the United States, with 85.2 gigawatts of net generating capacity [DOE 87c].

Demand for uranium by utilities may be directly linked to the fuel requirements of currently operating or planned nuclear power plants. The status of U.S. nuclear power plants as of December 31, 1986 is shown in Table 4-1. Because of the long lead times associated with the ordering, construction and permitting of nuclear power plants, it is extremely unlikely that any additional orders for new nuclear plants will result in operable capacity before 1998 [DOE 87c]. Historical consumption data for utilities are not available. The closest approximation is statistics on deliveries by utilities of uranium to DOE enrichment plants. Deliveries for 1977 to 1986 are listed in Table 4-2.

Exports

Exports of uranium by producers have declined steady since 1979. In 1984, at 1,100 tons of U_3O_8, exports were the lowest since 1976. Current commitments for exports total only 4,400 tons for 1985-2000 [DOE 85b]. Exports for 1977-1986 are shown in Table 4-3.

Table 4-1: Status of U.S. Nuclear Power Plants as of December 31, 1986.

Status	Number of Reactors	Net Summer Capability (GWe)
Operable		
In Commercial Operation	98	82.9[a]
In Power Ascension	2	2.3
Total	100	85.2
In Construction Pipeline		
In Low-Power Testing	7	7.1
Under Construction	14	16.1
Indefinitely Deferred	5	6.1
Total	26	29.4
Reactors on Order	2	2.2
Total	128	116.8

[a] Three Mile Island 2, Dresden 1, and Humboldt Bay are not included. The Hanford-N reactor is included.

Source: (DOE 87c)

Table 4-2: Deliveries of Uranium to DOE Enrichment Plants by Domestic Utilities.

	Amount Delivered (Short Tons U_3O_8)		
Year	U.S. Origin	Foreign Origin	Total
1977	14,250	700	14,950
1978	11,950	750	12,700
1979	15,450	1,600	17,050
1980	11,150	1,200	12,350
1981	10,050	1,150	11,200
1982	13,550	3,000	16,550
1983	10,850	2,200	13,050
1984	8,400	5,750	14,150
1985	8,950	3,800	12,750
1986	8,300	5,350	13,650

Sources: (DOE 84a, DOE 85b, DOE 86b, DOE 87b)

Table 4-3: Exports of Uranium[a] (Thousand Short Tons of U_3O_8).

	Historical Exports	
Year	Total Exports	Producer Exports
1967	N.A.	0.7
1968	N.A.	0.8
1969	N.A.	0.5
1970	N.A.	2.1
1971	N.A.	0.2
1972	N.A.	0.1
1973	N.A.	0.6
1974	N.A.	1.5
1975	N.A.	0.5
1976	N.A.	0.6
1977	N.A.	2.0
1978	N.A.	3.4
1979	N.A.	3.1
1980	N.A.	2.9
1981	N.A.	2.2
1982	3.10	2.2
1983	1.65	N.A.
1984	1.10	N.A.
1985	2.65	N.A.
1986	0.80	N.A.

Sources: (DOE 84a, DOE 85a, DOE 87b)

[a] Total exports include exports by utilities, producers and other suppliers (reactor manufacturers and fuel fabricators). Data for exports by utilities and other suppliers were not collected until 1982.

N.A. = Not Available.

Pricing

Two basic types of pricing arrangements dominate the procurement of uranium: contract pricing and market pricing. In contract pricing, prices and their escalation factors, if any, are determined when the contract is signed. In market pricing, the price is commonly determined just before delivery and is based on the market price prevailing at that time. Some market price contracts contain a floor price, set at the time the contracts are signed, that serves as a minimum on the eventual settled price. Pricing arrangements that cannot be classified as either market or contract pricing are grouped in a third category. This other category refers primarily to supply arrangements wherein the buyer has direct control of a uranium property. Among 1986 deliveries of uranium, 36 percent used contract pricing, 49 percent used market pricing, and 15 percent used other pricing arrangements [DOE 87a].

The concept of market pricing is probably the most complex of the three types. While it is common to refer to a market or spot price for uranium, there is actually no centralized spot or futures market. Contracts are negotiated between a producer and a utility either, through a middleman such as a nuclear power plant manufacturer or through a broker. The price commonly referred to as the spot price for uranium is a price published by the Nuclear Exchange Corporation (NUEXCO), the principal uranium broker. This price, which NUEXCO calls the uranium exchange value, is a monthly estimate of the price at which transactions for immediate delivery could have been concluded as of the last day of the month [DOE 87c].

Historical Prices and Pricing Mechanisms

Until 1968, prices were largely determined by the Atomic Energy Commission. In the early years of the commercial uranium market, 1968 through 1973, the price of uranium declined and remained low despite conditions of excess long-term demand. Beginning in 1973, the price of uranium jumped due to immediate industry requirements, a surge in long term contracting resulting from changes in procedures for enrichment service contracts, and other factors.

At the same time, the terms under which long-term contracts were priced began to change. Until 1973, contracting was typically under fixed price contracts with inflation provisions. However, in 1973, producers resisted signing fixed price contracts, because, as a result of production cost increases, they were losing money on previous fixed price contracts, and because they anticipated price rises in the future. In 1974, when the uranium market became a seller's market, market price contracts became popular. These contracts were written to guarantee the producer a base rate-of-return on investment. In a short time, market price contracts became the norm.

In 1979-1980, the seller's market for uranium ended, and the uranium market witnessed a sharp decline in prices due to postponements and cancellations of nuclear reactors, the build-up of uranium inventories at utilities, and the growing competition from low-priced imported uranium. A sharp decline in the nominal price of uranium began in 1980, dropping from over $40 per pound of U_3O_8 at the end of 1979 to $23.50 per pound by August 1981. In real terms (adjusted for inflation), the price had actually begun dropping in 1976. The price in August 1981 in constant dollars was half of what it had been in 1976. The price has continued to drop slowly from 1980 through 1987 [DOE 87a].

The average contract prices for deliveries made between 1982 and 1986 is given in Table 4-4. Market price settlements for the same period are included with contract prices because, as settled prices, they are similar to contract prices. This procedure gives a generally comprehensive average price for actual deliveries (except for deliveries made under litigation settlements or other pricing arrangements). Historical NUEXCO exchange values, or "spot prices" are listed in Table 4-5.

Prices of Foreign-Origin Uranium

Prices of imported uranium are substantially lower than domestic contract prices. The average price paid for 1986 deliveries of imported uranium was $20.07 per pound of U_3O_8, approximately one-third less than the amount paid for domestic-origin uranium, $30.01 [DOE 87a]. Table 4-6 shows the average price paid by domestic customers for 1981 to 1986 deliveries of foreign-origin uranium.

4.2.2. Sources of Supply

The uranium used to fuel nuclear reactors is supplied by domestic and foreign producers, inventories held by utilities, and secondary market transactions such as producer-to-producer sales, utility-to-utility sales and loans, and utility-to-producer sales. The role of each is described in the following sections.

Table 4-4: Average Contract Price and Market Price Settlements for Actual Deliveries 1982-1986.
(Year of Delivery Dollars)

Year of Delivery	(a) Reported Price ($/lb)	Quantity: Price Reported (million lbs)	Quantity: Price Not Reported (million lbs)	(a)(b) Adjusted Price ($/lb)
1982	38.37	16.7	2.6	39.82
1983	38.21	17.4	0.5	37.81
1984	32.65	16.1	0.3	32.38
1985	31.43	15.8	0.7	30.79
1986	30.01	12.1	0.0	30.01

Notes: (a) Price excludes uranium delivered under litigation settlements.

(b) The adjusted price is a weighted average of reported prices and price estimates for respondents to the EIA survey who did not supply price information. Price estimates are based on regression analysis of the reported prices.

Source : (DOE 87b)

Table 4-5: Historical Nuexco Exchange Values. (Nominal Dollars Per Pound of U_3O_8)

Year	As of December 31
1968	5.50
1969	6.20
1970	6.15
1971	5.95
1972	5.95
1973	7.00
1974	15.00
1975	35.00
1976	41.00
1977	43.00
1978	43.25
1979	40.75
1980	27.00
1981	23.50
1982	20.25
1983	22.00
1984	15.25
1985	17.00
1986	16.75
1987	16.55

Source: [NUEXCO 87]

Table 4-6: Prices for Foreign-Origin Uranium.

Year	Average Price Per Pound of U_3O_8 (Current Dollars)	Amount of U_3O_8 (Thousand Short Tons)	Total Import Delivery Commitments Sampled (Percent)
1981	32.90	2.20	67
1982	31.05	2.00	53
1983	26.16	4.10	100
1984	21.08	5.55	89
1985	20.08	5.35	91
1986	20.07	6.40	95

Source: [DOE 87b].

Domestic Production

Table 4-7 shows trends in domestic production of uranium concentrate from 1947 to 1986, by state. Total production was relatively constant at 10,500 to 13,000 tons per year until 1977, when it began an increase that peaked in 1980 at 21,852 tons. Production has declined almost every year since, reaching only 6,753 tons in 1986 [DOE 87b].

Coinciding with the overall decline in domestic production is a decline in the share of production represented by conventional mills. Historically, conventional milling accounted for, on average, approximately 70 percent of U.S. production. By 1985, the conventional share of production had fallen to a low of 53.8 percent, but in 1986 it rose to 65.6 percent (Table 4-8). This increase in market share is the result of an increase in the U_3O_8 content of the ore being milled. Only high grade ores can be cost-effectively milled under current market conditions.

By contrast, non-conventional uranium production has not declined as severely, and the share of uranium produced by non-conventional methods has increased consistently. This is explained by the low marginal cost of producing uranium as a by-product or from the water in a closed underground mine. According to an unofficial 1983 DOE estimate, 50 percent of non-conventional production is from by-product recovery, 40 percent is from *in situ* leaching, and ten percent from heap leaching and mine water processing. Wet process phosphoric acid, copper waste dumps, and bellyrium ores constitute by-product methods of production of U_3O_8. The second significant non-conventional source is *in situ* leaching. In 1986, by-product and *in situ* leaching, together, accounted for 79 percent of the total non-conventional annual production of U_3O_8. Other less important sources include mine water, and heap leaching, which accounted for 21 percent of total non-conventional production in 1986.

The result of the decline in demand for conventional production has been severe overcapacity and mill shutdowns [DOE 85a]. Milling capacity, which almost doubled between 1975 and 1980 when the price of uranium was high and optimistic demand forecasts stimulated investment in milling facilities, once enjoyed a utilization rate of 94 percent [JFA 85a]. In December 1986, capacity utilization was about 32 percent at operating mills. The number of operating mills has declined dramatically also, from 20 in 1981 to a low of two in June 1985 [DOE 85a]. NUEXCO indicates that six mills operated in 1987, and Volume 2 of the *Environmental Impact Statement* reports that only four were operating

Table 4-7: Total Uranium Concentrate Production, 1947-1986.

Year(s)	Colorado	New Mexico	Texas	Utah	Wyoming	Others(a)	Total
1947-65	29,652	54,301	(b)	28,924	18,449	8,380	139,706
1966	1,423	5,076	(b)	(c)	2,248	1,842	10,589
1967	1,340	5,933	(b)	(c)	2,667	1,313	11,253
1968	1,614	6,192	(b)	(c)	2,873	1,689	12,368
1969	1,678	5,943	(b)	(c)	3,063	925	11,609
1970	(c)	5,771	(b)	(c)	3,654	3,480	12,905
1971	(c)	5,305	(b)	(c)	3,487	3,481	12,273
1972	(c)	5,464	(b)	(c)	4,216	3,220	12,900
1973	(c)	4,634	(b)	(c)	5,159	3,442	13,235
1974	(c)	4,951	(b)	(c)	3,767	2,810	11,528
1975	(c)	5,191	(c)	(c)	3,447	2,962	11,600
1976	(c)	6,059	(c)	(c)	4,046	2,642	12,747
1977	(c)	6,779	(c)	(c)	4,990	3,170	14,939
1978	(c)	8,539	(c)	(c)	5,329	4,618	18,486
1979	(c)	7,423	2,651	(c)	5,452	3,210	18,736
1980	(c)	7,751	3,408	(c)	6,036	4,657	21,852
1981	(c)	6,206	3,141	(c)	4,355	5,535	19,237
1982	(c)	3,906	2,131	(c)	2,521	4,876	13,434
1983	(c)	2,830	1,600	(c)	2,630	3,519	10,579
1984	(c)	1,458	1,310	(c)	1,560	3,113	7,441
1985	(c)	694	1,085	(c)	1,214	2,667	5,657
1986	(c)	376	1,293	(c)	317	4,768	6,753

Notes: (a) Includes, for various years, Arizona, Colorado, Florida, Louisiana, South Dakota, Texas, Utah, and Washington.

(b) Data were not collected.

(c) Included in the "others" category.

Table 4-8: Production of Uranium Concentrate by Conventional Mills and other Sources, 1978-1986 (short tons U3O8)

Year	Conventional Production	Other Production(a)	Total Production	Conventional Production As a Percent of Total	Average U3O8 Concentration of Ore Milled (%)
1978	17,172	1,315	18,486	93	0.131
1979	16,877	1,860	18,736	90	0.105
1980	18,903	2,950	21,852	87	0.118
1981	15,998	3,239	19,237	83	0.115
1982	10,447	2,988	13,434	78	0.119
1983	7,760	2,820	10,579	73	0.128
1984	4,813	2,628	7,441	65	0.112
1985	3,042	2,615	5,657	54	0.161
1986	4,427	2,327	6,753	66	0.336

Note: (a) Saleable U3O8 obtained from _in situ_ leaching and as a byproduct of other processing.

Source: [DOE 87b]

in 1988 (Table 4-13), but industry sources predict that the number of operating mills could drop to three within two to five years. Uranium mill capacities and utilization levels are listed in Table 4-9.

Imports

A second source of uranium is the import market. Until 1975, foreign uranium was effectively banned from U.S. markets by a Federal law prohibiting the enrichment of imports for domestic use. This restriction was lifted gradually after 1975, and was eliminated completely in 1984. From 1975 through 1977, imports amounted to a small portion of total domestic requirements, with U.S. exports exceeding imports in each year from 1978 through 1980. By 1986, however, imports supplied 44 percent of U.S. requirements. Table 4-10 lists U.S. imports from 1974 through 1986 [DOE 87a].

The primary sources of U.S. uranium imports have been Canada, South Africa and Australia. In 1986, 59 percent of U.S. uranium imports were from Canada, and 41 percent were from Australia and South Africa [DOE 87a].

Forecasts of import penetration call for the import share to grow through the 1990s. The Department of Energy projects that without government intervention, between the year 1990 and 2000 imports will range between 50 and 64 percent of domestic utility requirements, depending on demand levels.

Inventories

Utilities hold uranium inventories in order to meet changes in the scheduling of various stages of the fuel cycle, such as minor delays in deliveries of uranium feed. Uranium inventories also protect the utilities against disruption of nuclear fuel supplies. The average "forward coverage" currently desired by domestic utilities (in terms of forward reactor operating requirements) is 18 months for natural uranium (U_3O_8) and seven months for enriched uranium hexafluoride (UF_6) [DOE 85a].

Table 4-11 lists inventories of commercially-owned natural and enriched uranium held in the United States as of December 31, 1984, 1985, and 1986. DOE-owned inventories are not included. The uranium inventory owned by utilities alone at the end of 1984 represented almost four years of forward coverage.

Table 4-9: Uranium Mill Capacity (Tons of Ore Per Day).

Year	Total Capacity	Operating Capacity	Operating Capacity Utilization Rate	Total Capacity Utilization Rate
1981	54,050	49,800	83	77
1982	55,050	33,650	74	45
1983	51,650	29,250	58	33
1984	48,450	19,250	64	25
1985	47,250	6,550	78	11
1986	42,650	11,650	32	9

Source: (DOE 87a)

Table 4-10: Imports of Uranium Concentrate for Commercial Uses, 1974-1986 (Short Tons U_3O_8)

Year of Delivery	Imports
1974	0
1975	700
1976	1,800
1977	2,800
1978	2,600
1979	1,500
1980	1,800
1981	3,300
1982	8,550
1983	4,100
1984	6,250
1985	5,850
1986	6,750

Source: (DOE 87b)

Table 4-11: U.S. Commercially-Owned Uranium Inventories as of December 31, 1984, 1985, and 1986 (Short Tons U_3O_8 Equivalent)

	1984		1985		1986	
Owner Category	Natural	Enriched	Natural	Enriched	Natural	Enriched
Utilities	48,350	31,750	44,100	32,450	41,550	30,900
Suppliers	12,000	500	11,150	700	12,400	450
TOTAL	60,350	32,250	55,250	33,150	53,950	31,350

Source: [DOE 87b]

Secondary Market Transactions

The secondary market for uranium includes producer-to-producer sales, utility-to-utility sales and loans, and utility-to-producer sales. The secondary market, by definition, does not increase the supply of uranium, only the alternatives for purchasing it. As such, secondary transactions can have a significant impact on the demand for new production and on the year-to-year changes in inventories. The secondary market has been significant in recent years. During 1986, sales of 6,800 tons of U_3O_8 equivalent were made between domestic utilities and suppliers in the secondary market.

4.2.3 Industry Structure and Performance

The number of firms participating in the domestic uranium milling industry declined between 1977 and 1985, but has since increased. In 1977, 26 companies owned active uranium mills. In 1983, the number had fallen to 11, and in June 1985, there were only two [DOE 87b]. In 1987, six companies operated six mills and by August 1988, only four mills continued to operate. The status of the industry can also be seen in trends in employment and capital expenditures (Table 4-12). Capital expenditures in 1986 were $1 million, compared to $72 million in 1981 (1986 dollars) [DOE 87a, DOE 87b]. Employment in 1984 was 513 person-years, compared to 2,367 in 1981 [DOE 87a].

Mining and milling production data for individual companies are collected by DOE but are not available to the public. However, some data on operating status are published. These are listed, by firm and mill, in Table 4-13.

A wide variety of companies are represented within the uranium industry. In the industry's early years, holdings were dominated by independent mining and exploration companies. Since then, mergers, acquisitions, and the entry of conglomerates have considerably altered industry structure. During the 1970s, the oil embargo and forecasts of growing demand for nuclear power made entry into the uranium market attractive to oil companies and utilities. Of the six mills operating in 1987, three were owned by foreign mining companies, one an American mining company, one by a subsidiary of an oil company, and another by a subsidiary of a chemical company. These ownership characteristics influence the current and future financial viability of the industry. The desire of the parent companies to weather a downturn in the uranium market and to retain an interest in producing

Table 4-12: Capital Expenditures, Employment, and Active Mills: Conventional Uranium Milling Industry.

Year	Capital Expenditures (Million Constant 1986 $)	Employment (Person-Years)	Number of Active Mills At Year-End
1981	72	2,367	---
1982	12	1,956	14
1983	3	1,518	12
1984	8	987	8
1985	9	514	4
1986	1	513	6

Sources: (DOE 87a, DOE 87b)

Table 4-13. Operating status of licensed conventional uranium mills as of June, 1989.
June 1989.(a)

State/Mill	Owner	Operating Status(b)	Reclamation Status(c)
Colorado			
Canon City	Cotter Corp.	Standby	Future
Uravan	Umetco Minerals	Standby	In Progress
New Mexico			
L-Bar	BP American	Decommission	Cover in Place
Churchrock	United Nuclear	Decommission	In Progress
Bluewater	Anaconda	Decommission	In Progress
Ambrosia Lake	Kerr-McGee	Standby	In Progress
Homestake	Homestake	Active	Future
South Dakota			
Edgemont	TVA	Decommission	Completed
Texas			
Panna Maria	Chevron	Active	Future
Conquista	Conoco/Pioneer	Decommission	In Progress
Ray Point	Exxon	Decommission	Completed
Utah			
White Mesa	Umetco Minerals	Active	Future
Rio Algom	Rio Algom	Standby	In Progress
Moab	Atlas	Decommission	In Progress
Shootaring	Plateau Resources	Standby	Future
Washington			
Dawn	Dawn Mining	Decommission	In Progress
Sherwood	Western Nuclear	Standby	Future
Wyoming			
Lucky Mc	Pathfinder	Standby	Future
Split Rock	Western Nuclear	Decommission	In Progress
Umetco	Umetco Minerals	Decommission	In Progress
Bear Creek	Rocky Mt. Energy	Decommission	In Progress
Shirley Basin	Pathfinder	Active	Future
Sweetwater	Minerals Expl.	Standby	Future
Highland	Exxon	Decommission	Cover in Place
FAP	American Nuclear Corporation	Decommission	Unknown
Petrotomics	Petrotomics	Decommission	Design Approval

(a) Data obtained from conversations with cognizant personnel in Agreement States and the NRC, comments submitted by individual companies and the American Minining Congress during the public comment period, and site visits. Does not include mills licensed but not constructed.

(b) Active mills are currently processing ore and producing yellowcake. Standby mills are not currently processing ore but are capable of restarting. At mills designated by "Decommission", the mill structure has been or is being dismantled and no future milling will occur.

(C) Terms to describe reclamation status are as follows: "Future", impoundment is being maintained to accept additional tailings and reclamation activivities have not yet started; "Design Approval Pending", final disposal design has been submitted for regulatory approval and reclamation activities are underway; "In Progress", active reclamation has begun but final cover is not completed; Cover in Place", final cover has been completed but final stabilization has not been completed; and "Completed", disposal and stabilization have been accomplished in accordance with Umtrca standards.

properties is a function of their perception of the prospects for long-term profitability in domestic uranium operations. Some firms continue to invest and to acquire properties, while others withdraw from an extremely soft market. Foreign firms appear to have adopted a longer term viewpoint than have some of their domestic counterparts. It is likely that the industry will continue to undergo structural change. This change will depend on domestic and foreign demand, costs of production, and the industry's ability to compete with lower-priced imports [DOE 87a].

4.2.4 Economic and Financial Characteristics

4.2.4.1 Employment Analysis

Department of Energy estimates of employment in the uranium milling industry from 1984 to 1986 are listed in Table 4-14. Additional detail at the state level was obtained through discussions with staff of the departments of mining or natural resources in the states with uranium mills. This is provided in the following paragraphs. Historically, New Mexico and Wyoming have been the nation's leading producers of uranium and have jointly been responsible for an estimated 70 to 75 percent of total uranium concentrate production. Following the peak production period of 1981 and 1982, and since the onset of the production decline in the latter part of 1982, it is estimated that approximately 7000 jobs have been lost in New Mexico as production fell from 253 million tons in 1982 to 36 million in 1984 [NM 85].[1]

The trend in Wyoming has been similar. In 1980, seven uranium mine-mill complexes and one uranium mill employed a total of 2451 people. In 1981, employment dropped to 1361 people. In 1984, employment was down to 454 workers [WY 80, 81, and 84].

In Washington, before 1982 there were two mine-mill complexes: Midnight Mines (owned and operated by Dawn Mining Company) and the Sherwood Mine (owned by Western Nuclear, a subsidiary of Phelps Dodge Corporation). In 1981, Dawn employed 50 workers, and in 1982 it employed 42. In 1981, Sherwood employed 45 workers, while in 1982 it employed 14 miners plus 98 maintenance workers. Both mine-mill complexes are currently inactive and unemployment (estimated at 40 percent from 1982 to 1983) was estimated to be as high as 80 percent [WA 85].

---

[1] Employment and output estimates by state sources may not agree with those provided by the U.S. Department of Energy and presented elsewhere in this report, due to differences in data collection procedures.

Table 4-14: Employment in the U.S Uranium Milling Industry by State.

1984

State	Person-Years
Colorado	215
Wyoming	310
Arizona, New Mexico, Texas, Utah, Washington	462
TOTAL	987

1985

State	Person-Years
Colorado	W
Wyoming	128
Arizona	W
New Mexico	W
Other	W
TOTAL	128

1986

State	Person-Years
Arizona	0
Other	W
Total	W

W = Withheld

Source: (DOE 86, DOE 87b)

In Colorado, there were 508 mineral industry operations in 1980, 100 of which were engaged in the production of uranium. By 1985, however, there were only two mines or mine/mill complexes: Centennial and Schwartzwalder. In 1980, the uranium industry employed approximately 1594 individuals [Nugent 80], whereas it is estimated that the two operations now employ about 200 people [Co 85].

In Texas, there were, until recently, three mills: the Conquista Project (Conoco), Ray Point (Exxon) and the Panna Maria complex (Chevron). The Conquista complex, it is estimated, employed over 500 people during its peak period from 1979 to 1980, and the Panna Maria complex about 250 people during its peak period from 1981 to 1983. The Conquista Project and Ray Point have been closed and are being decommissioned. The Panna Maria was operating at the close of 1987, but at a considerably reduced rate. Employment there reached a low of seven to eight people in 1985. Current employment is unknown [TX 85].

4.2.4.2 Community Impact Analysis

The impact of trends in uranium milling on small communities dependent on uranium milling facilities tends to vary depending on the location of the mines, the importance of uranium mining and milling to the state, and the nature of the work force. Texas and Washington serve as interesting case studies.

In Washington, the uranium facilities are located primarily in the Spokane Indian Reservation. Mining soon became the main economic activity as the mining companies were under contractual obligation to draw 51 percent of their labor force from the Indian community. When the two Washington mine-mill complexes, Midnight Mines and Sherwood Mines, closed in 1983-1984, the unemployment rate rose to about 80 percent. This is perhaps partly attributable to the absence of any other mining activity on the reservation which might have absorbed some of the displaced workers. This high unemployment rate also suggests limited mobility on the part of miners and workers. Thus, in the case of Washington it would seem that the employment effects were concentrated, and felt largely by the Indian community which served as the principal source of labor for uranium mining and milling within the state [WA 85].

In Texas, by contrast, the community impacts of the uranium industry are less significant. Most uranium industry employees were originally farmers and ranchers, maintaining and upgrading their properties during the lifetime of their mining careers. Moreover, they were mostly a commuting work force so there was no residual pool of unemployed persons in the vicinity of the mines once the decline in employment took place in the early 1980s. There were no uranium mining communities as such in the State of Texas which were dependent on the mining and production of uranium for their subsistence. Moreover, many workers were absorbed by the then booming petroleum and lignite industries [TX 85].

In the case of both Colorado and Utah, the ability to absorb unemployed uranium workers is limited. In Colorado, this has been due to the depressed state of the mining industry in general within the state [CO 85]. In New Mexico, where uranium mining and milling are considered an important economic activity, there were areas of concentrated impact - such as Gallup, the Laguna Pueblo area and the Navajo Indian Reservation. The wide scale reduction in employment observed in recent years, the reduction in sales and sales tax revenues, the loss of severance payments, a significant amount of out-migration to Nevada and several other states, and a concomitant reduction in income tax revenue have combined to make the impact significant and state-wide as opposed to community-specific [NM 85].

4.2.4.3 Financial Analysis

Selected financial data for the domestic uranium industry for 1982 to 1986 are shown in Table 4-15. The data cover a subset of firms (the same firms for all years) that represent over 80 percent of the assets in the industry in each year. The firms included are those for which uranium operations could be separated from other aspects of the organization's business, and for which an acceptable level of consistency in financial reporting practices was available for all years. Financial data on the milling industry alone are not available.

As shown in Table 4-15, net income accruing to the uranium industry was positive in only two years, 1982 and 1983. The returns on assets (net income divided by total assets) in these years were 0.7 and 1.4 percent respectively, and aggregate net earnings totalled $69.8 million. In 1984, 1985, and 1986, the returns on assets were -10.3, -21.6, and -2.3 percent, and aggregate net losses reached $765.7 million. The loss in 1984 alone was $304.7 million on revenues of $608.9 million. Thus, the aggregate loss for the five years was $695.9 million. In 1977, 146 firms were involved in domestic

Table 4-15: Financial Statistics of the Domestic Uranium Industry, 1982-1986. (Dollars, millions)

	1982	1983	1984	1985	1986
Income Statement					
Operating Revenues	1069.5	857.9	608.9	581.5	444.9
Operating Income	15.9	77.3	-24.2	-37.2	-1.5
Net Income	24.1	45.7	-304.7	-419.4	-41.6
Source and Use of Funds					
Net Income	24.1	45.7	-304.7	-419.4	-41.6
Depreciation, Depletion, and Amortization	240.1	162.5	117.6	92.1	68.5
Deferred Taxes	11.0	2.1	-28.5	-112.8	-6.7
Other Funds Provided From Operations	65.7	9.4	157.8	207.5	60.5
Disposition of Property, Plant, and Equipment (Book Value)	7.0	30.8	231.7	366.6	25.8
Debt and Equity	343.9	15.2	77.5	125.0	144.6
Other Sources	23.0	151.1	167.1	253.4	174.6
Total Sources	714.8	416.8	418.5	512.4	425.7
Capital Expenditures (Property, Plant, and Equipment)	125.9	49.6	41.5	39.3	21.1
Debt Repayment	154.2	183.6	133.5	278.7	191.9
Other Uses	336.5	150.8	184.1	150.5	204.8
Total Uses	616.8	383.9	359.1	468.4	417.8
Change in Working Capital	98.0	32.9	41.4	43.9	8.1
Balance Sheet					
Current Assets (Less Inventory)	428.2	380.8	568.9	472.9	488.1
Inventory	435.0	416.0	430.9	367.8	352.2
Net PP&E	2119.5	1733.2	1507.4	705.8	600.4
Other Noncurrent Assets	575.9	727.3	445.0	397.2	330.9
Total Assets	3558.5	3257.2	2952.3	1943.7	1771.5
Current Liabilities	278.7	217.8	369.4	318.7	229.3
Deferred Liabilities	1533.0	1730.7	1744.1	1016.3	1008.9
Total Liabilities	1811.8	1948.4	2113.6	1335.0	1238.1
Equity	1746.8	1308.7	838.7	608.6	533.4
Total Liabilities	3558.5	3257.2	2952.3	1943.7	1771.5
			Ratios (Percent)		
Rates of Return					
Net Income to Total Assets	0.7	1.4	-10.3	-21.6	-2.3
Net Income to Total Equity	1.4	3.5	-36.3	-68.9	-7.8
Net Income to Net Investment in Place	1.1	2.1	-17.3	-43.5	-5.2
Fund Flow Measures					
Additions to PP&E to Total Sources of Funds	17.6	11.9	10.4	7.7	5.0
Leverage Measures					
Deferred Liabilities to Total Equity	87.8	132.2	208.0	167.0	189.1
Deferred Liabilities to Total Assets	43.1	53.1	59.1	52.3	57.0
Liquidity Measures					
Current Ratio	3.1	3.7	2.7	2.6	3.7
Liquidity Ratio	1.5	1.7	1.5	1.5	2.1

Source (DOE 87a)

uranium exploration, 135 in mining and 26 in milling. In contrast, only 31 firms were actively engaged in exploration, 11 in mining and 5 in milling toward the end of 1986. Of these firms, only 27 percent had positive net income after meeting operating expenses and other obligations such as payment of taxes and recovery of depletion, depreciation and amortization. Fifty-five percent reported net losses; the remaining 18 percent either had left the industry or had no data to provide.

Most of the financial improvement in 1986 stemmed from the slowdown or the completion of writeoffs of discontinued operations, revaluation of assets and abandonments. The domestic uranium industry is significantly smaller than before, and its financial state will depend on higher product prices or demand [DOE 87a].

Company-specific information on uranium production, revenues, profits, and plans is provided in the following paragraphs.

Homestake Mining Company

Homestake Mining Company owns one conventional uranium mine and a 3400 ton per day mill in Grants, New Mexico. During 1984, production of uranium was reduced to the minimum level at which satisfactory unit costs could be maintained. Mine production has been confined to one mine operating on a five-day-week schedule for ten months of the year. Uranium concentrate was also recovered from solution mining and ion-exchange. In 1986, uranium accounted for 14 percent of the company's revenues, and 21 percent of operating earnings. The high profitability of the sector for the year is attributed to existing contracts, expiring in 1987, that provide for sale prices above current spot prices and production costs. Selected financial statistics are presented in Table 4-16 [AR 84, AR 85, AR 86].

Rio Algom

Rio Algom is a Canadian corporation engaged in the mining of a wide variety of materials, including copper, steel, and uranium. In 1986, uranium operations accounted for 26 percent of corporate revenue, but most (89 percent) was from Canadian production. In the United States, the company owns one uranium mine and a 750 ton per day mill in La Sal, Utah.

Table 4-16: Homestake Mining Company Uranium Operations, 1982 Operations

	1982	1983	1984	1985	1986
Revenues (millions dollars)	63.70	58.60	57.90	68.20	49.80
Operating Income (millions dollars)	15.60	11.40	19.60	22.80	12.70
Sales of U308 (millions pounds)	N/A	1.13	1.13	0.94	1.05
Sales Price Per Pound of U308 (a)	46.20	49.76	51.21	49.70	47.50
Depreciation, Depletion, and Amortization (millions dollars)	20.00	14.30	4.40	12.50	4.30
Additions to Property, Plant, and Equipment (millions dollars)	1.00	0.00	0.70	0.00	0.00
Identifiable Assets (millions dollar	80.00	73.00	66.90	43.70	24.90

(a) Prices based on long-term contracts that were to expire in 1986 and 1987.

N/A - not available

Source: (AR 84b, 85b, 86b)

In 1986, the company produced 457 tons of uranium oxide from its Utah mine. The mine operated at approximately 50 percent of capacity in 1986, while the mill operated at capacity due to a significant amount of toll milling [AR 86].[2] In 1987, the La Sal mill produced about 350 tons of uranium oxide using both company ore and ore from the Thornberg mine. The mill was placed on standby in September, because the Lisbon and Thornberg mines' reserves are depleted [EPA 89]. Selected financial statistics on Rio Algom uranium operations are presented in Table 4-17.

Plateau Resources Limited

Plateau Resources, a wholly owned subsidiary of Consumers Power Co., was organized in 1976 to acquire, explore, and develop properties for the mining, milling, and sale of uranium. All operations were suspended in 1984 because of depressed demand and all uranium assets were written down by $46 million after taxes in 1984 and $21 million in 1985, to an estimated net realizable value of approximately $34 million. There is no assurance that the amount will ever be realized however. The company's 800 ton per day mill at Ticaboo, Utah, which was constructed in 1980 and 1981, has never been active. It does, however, remain on standby and could be activated [AR 84, 85, 86].

Western Nuclear

Western Nuclear, a subsidiary of Phelps Dodge Corporation, owns two mine and mill complexes, one in Wyoming and one in Washington. The capacities of its mills are 1700 and 2000 tons per day, respectively. The Wyoming mill has been on standby since the early 1980s, and decommissioning is anticipated. The Washington complex operated intermittently from 1981 through 1984. In late 1984, Phelps Dodge wrote off its entire "Energy" operation, of which Western Nuclear was a major part [AR 84, AR 85].

4.2.5 Industry Forecast and Outlook

This section presents projections of total U.S. utility market requirements, domestic uranium production, from both conventional and non-conventional sources, imports, employment and electricity consumption. Developed for a 14-year period (1987-2000), these projections are considered "near term." A basic assumption of the near term projections is that current market

---

[2] "Toll milling" is the processing of ore from another company's mines on a contract basis.

Table 4-17: Rio Algom Uranium Operations, 1981-1986.
(Canadian Dollars, Millions)

	1981	1982	1983	1984	1985	1986
Revenues	281.9	281.7	297.6	368.1	368.3	349.2
Operating Income	69.2	60.3	76.1	86.9	88.3	77.1
Capital Expenditures	17.3	13.7	87.8	(2.1)	3.8	60.9
Assets	372.1	427.8	752.9	774	775.4	977.1
Depreciation, Amortization	30.7	28.1	29.9	37.6	36.2	39.5
			Tons U308			
Total Production	3,900	3,550	3,400	4,111	4,065	4,107
Canadian Production	N/A	N/A	3,233	3,800	3,700	3,650
U.S. Production	N/A	N/A	167	311	365	457

Source: AR 87b

conditions, as defined by the Department of Energy's Energy Information Administration (DOE, EIA), will continue unchanged through the end of this century. This section is based on the reference case projections in EIA's *Domestic Uranium Mining and Milling Industry: 1986 Viability Assessment* [DOE 87a].

4.2.5.1 Projections of Domestic Production

The EIA's Reference case[3] forecasts for 1987-2000 are based on the output of EIA's economic model, Domestic Evaluation of Uranium Resources and Economic Analysis (EUREKA). The EUREKA model's methodology goes beyond the scope of this study; it is fully described in Appendix C of the *1986 Viability Assessment.* The EIA examines future developments in the domestic uranium industry and in the domestic and international uranium markets under current market conditions and under certain hypothetical supply disruption scenarios[4]. The current market conditions are generally the same as those presented in Sections 4.2.1-4.2.4 of this study and are based on historical trends in the domestic uranium industry as outlined in both the *Viability Assessment* and the EIA's *Uranium Industry Annual 1986.* In addition to the uranium prices, production and imports as well as the exploration expenditures, capital expenditures, and employment data developed for inclusion as "current market conditions," the EIA includes one important assumption: that the Act of Congress forbidding imports of uranium from South Africa and Namibia will be enforced[5]. Also taken into account by DOE are assumptions on future electricity generation, fuel burnup levels, enrichment in tails assay, and inventory drawdowns.

---

[3] Prior to the *1986 Viability Assessment*, EIA published two reference cases: a Lower Reference case and an Upper Reference case, each with a low, a mean, and a high range of projected values. In 1986, however, only the Lower Reference case was published. It is referred to simply as the Reference case. As before, low, mean and high projected values were produced by EIA. This study uses the mean. The Reference case in the *1986 Viability Assessment* uses the underlying assumptions for the Lower Reference case described in *Commercial Nuclear Power 1987: Prospects for the United States and the World* [DOE 87a].

[4] These scenarios, the "current disruption status" scenario and the "projected disruption status" scenario, are used to test the viability of the U.S. uranium industry, to examine the ability of this industry to respond to an abrogation of various fractions of contracts for uranium imports intended for domestic end use. Both of these bear only tangentially on this study and will not be discussed further here.

[5] The U.S. Congress passed the Comprehensive Anti-Apartheid Act of 1986 on October 2, 1986. Section 309 of that Act forbade the import into the United States of uranium ore or concentrate of South African of Namibian origin after January 1, 1987. However, natural or enriched uranium hexafluoride from these countries may be imported, according to a regulation issued by the U.S. Department of the Treasury on which the U.S. Nuclear Regulatory Commission has concurred [EPA87b].

4.2.5.2 **Near-Term Projections**

Total domestic production of U_3O_8, from both conventional and non-conventional uranium sources, for 1980-1986, is shown in tabular form in Table 4-18, along with reference case projections for the period 1987-2000. Annual domestic production peaked at 21,900 short tons after milling[6] in 1980, and declined to 6,750 short tons in 1986. Production is projected to remain well below the 1980 peak. For example, EIA has projected domestic U_3O_8 production in 1992 at 6,450 short tons, while output in the year 2000 is estimated at 7,500 short tons. Annual domestic production from conventional mining sources (i.e., from milling ore obtained from underground or open-pit mines, which historically has accounted, on average, for roughly 70 percent of total annual domestic production) has fallen more steeply: from 85 percent in 1980 to 53 percent in 1985. However, it increased from its 1985 level of 3,275 short tons to 5,825 short tons in 1986. As was stated in section 4.2.2, this increase was due to an increase in the U_3O_8 concentration of the ore milled in that year.

Changes in the market, such as the legislative import ban on South Africa and Namibia, could influence conventional production much more than non-conventional U_3O_8 production, because non-conventional U_3O_8 producers tend to have lower marginal costs of production than do conventional producers. Therefore, production from non-conventional sources tends to be less affected by fluctuations in uranium market prices. Wet process phosphoric acid, copper waste dumps, and bellyrium ores constitute by-product methods of production of U_3O_8. The second significant non-conventional source is *in situ* leaching. By-product and *in situ* leaching both accounted for 79 percent of the total non-conventional annual production of U_3O_8 in 1986. Other less important

---

[6] All U_3O_8 production data in this chapter is after milling and excludes U_3O_8 which is not recovered from the ores in milling. In recent years, milling recovery rate has been between 95-97 percent. In this study, it is assumed to be 95 percent.

Table 4-18: Annual and Projected Domestic Production and Imports of Yellow Cake, 1980-2000.
(in thousands of short tons)

Year	Total Production	% Annual Change	Conventional Production	% Annual Change	Percent Of Total	Non-Conventional Production	% Annual Change	Percent Of Total	Average Grade of Domestic Ore (%)	Imports	% Annual Change
1980	21.90	-	18.95	-	86.5%	2.95	-	13.5%	0.118	1.80	-
1981	19.20	-12.3%	15.96	-15.8%	83.1%	3.24	9.8%	16.9%	0.115	3.30	83.3%
1982	13.40	-30.2%	10.41	-34.8%	77.7%	2.99	-7.7%	22.3%	0.119	8.55	159.1%
1983	10.60	-20.9%	7.78	-25.3%	73.4%	2.82	-5.7%	26.6%	0.128	4.10	-52.0%
1984	7.45	-29.7%	4.82	-38.0%	64.7%	2.63	-6.7%	35.3%	0.112	6.25	52.4%
1985	5.65	-24.2%	3.03	-37.1%	53.6%	2.62	-0.4%	46.4%	0.161	5.85	-6.4%
1986	6.75	19.5%	4.42	45.9%	65.5%	2.33	-11.1%	34.5%	0.336	6.75	15.4%
1987	*6.50*	-3.7%	*4.11*	-7.1%	63.2%	*2.39*	2.8%	36.8%	0.284	*4.85*	-28.1%
1988	*6.85*	5.4%	*4.39*	7.0%	64.1%	*2.46*	2.7%	35.9%	*0.200*	*5.10*	5.2%
1989	*7.00*	2.2%	*4.48*	1.9%	64.0%	*2.52*	2.6%	36.0%	*0.200*	*6.40*	25.5%
1990	*6.55*	-6.4%	*3.96*	-11.5%	60.5%	*2.59*	2.6%	39.5%	*0.200*	*7.60*	18.7%
1991	*6.15*	-6.1%	*3.50*	-11.7%	56.9%	*2.65*	2.5%	43.1%	*0.200*	*8.70*	14.5%
1992	*6.45*	4.9%	*3.73*	6.7%	57.9%	*2.72*	2.4%	42.1%	*0.200*	*8.65*	-0.6%
1993	*6.90*	7.0%	*4.12*	10.3%	59.7%	*2.78*	2.4%	40.3%	*0.200*	*8.60*	-0.6%
1994	*7.20*	4.3%	*4.35*	5.7%	60.5%	*2.85*	2.3%	39.5%	*0.200*	*8.15*	-5.2%
1995	*7.20*	0.0%	*4.29*	-1.5%	59.6%	*2.91*	2.3%	40.4%	*0.200*	*8.60*	5.5%
1996	*7.45*	3.5%	*4.55*	6.1%	61.1%	*2.90*	-0.3%	38.9%	*0.200*	*9.35*	8.7%
1997	*7.50*	0.7%	*4.60*	1.1%	61.3%	*2.90*	0.0%	38.7%	*0.200*	*9.75*	4.3%
1998	*7.45*	-0.7%	*4.55*	-1.1%	61.1%	*2.90*	0.0%	38.9%	*0.200*	*10.15*	4.1%
1999	*7.55*	1.3%	*4.65*	2.2%	61.6%	*2.90*	0.0%	38.4%	*0.200*	*10.05*	-1.0%
2000	*7.50*	-0.7%	*4.60*	-1.1%	61.3%	*2.90*	0.0%	38.7%	*0.200*	*9.75*	-3.0%

Notes: Total historical and projected production of U3O8 are taken from (DOE87a). Data for 1980-1986 are actual, while data for 1987-2000 are projections based on the mean values for the Reference case. Projections of conventional production are calculated as the difference between total U3O8 production and non-conventional production, which is projected based on historical market share, capacity and unofficial EIA estimates.

Actual figures are bolded and projected figures are italicized.

sources include mine water, and heap leaching, which accounted for the remaining 21 percent of total annual non-conventional production in 1986.

The Reference case EIA projections of domestic U_3O_8 production through the year 2000 are based on a unit by unit review of nuclear power plants that are new, operating, under construction, or units for which orders have been placed and for which licenses are currently being processed. Under EIA's Reference case, nuclear generating capacity is expected to increase from 94.0 GWe in 1987 to 103.0 GWe in the year 2000 (Table 4-19). Historical and forecast data of total enrichment feed deliveries (demand), net imports, and total production are graphed in Figure 4-1 [DOE 87a]. Historical data and reference case projections for both conventional and non-conventional production of domestic uranium are plotted in Figure 4-2.

4.2.6 Evaluation of Forecasts and Uranium Market Demand

This section compares the EIA forecasts for total domestic production of U_3O_8 to total domestic uranium resources, and discusses the relationship of the EIA forecasts to total electricity generation.

4.2.6.1 Domestic Uranium Resources

The projection of domestic U_3O_8 production shown in Table 4-18 indicates that a total of a little over 98,000 short tons of U_3O_8 will be produced domestically over the next fourteen years. Over this time period, perhaps 38,400 short tons of U_3O_8 will be produced from by-product sources. A discussion of the potential for by-product technology is presented below, followed by a discussion of the extent of other domestic U_3O_8 resources.

By-Products

The most significant domestic source of by-product uranium is phosphate mining and processing. One source [JFA 1986] has estimated that current phosphate by-product production of uranium is at approximately one-fourth of its capacity. It is likely to remain below its capacity well into the next century. However, over the full fifteen-year period a substantial amount of U_3O_8 is likely to

FIGURE 4-1: SOURCES OF URANIUM SUPPLY
1980-1986 AND PROJECTIONS TO YEAR 2000

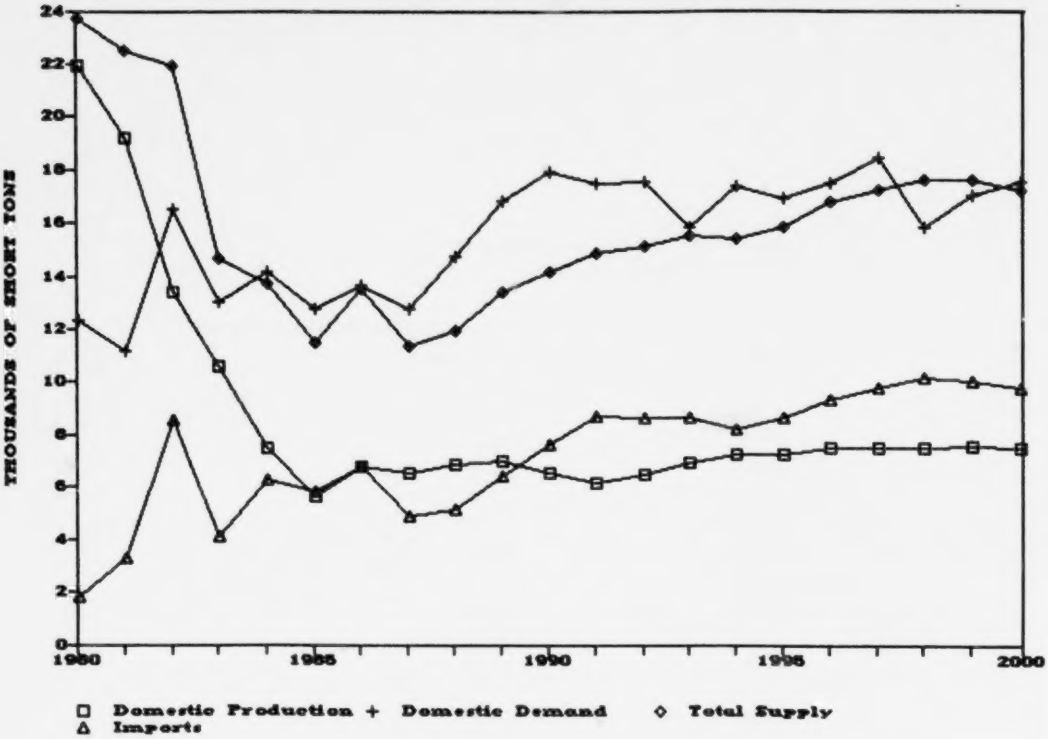


FIGURE 4-2: U.S. URANIUM PRODUCTION
1980-1986 AND PROJECTIONS TO YEAR 2000

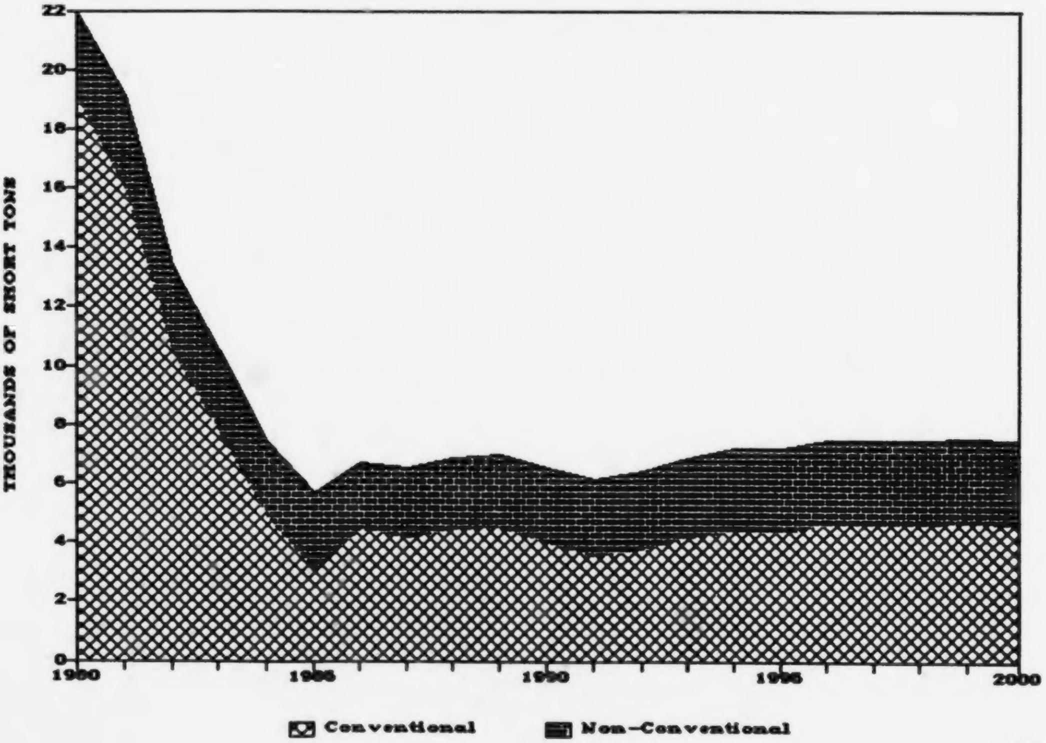


Table 4-19: Projected Nuclear Power Capacity
(Reference Case)

Year	Nuclear Power Capacity (GWe)
1987	94.0
1988	96.0
1989	99.6
1990	99.6
1991	101.9
1992	101.9
1993	101.9
1994	101.9
1995	101.9
1996	101.9
1997	101.9
1998	103.2
1999	103.2
2000	103.0

Source: (DOE 1987a:22)

be obtained from this technology, perhaps as much as 15,000 short tons, in the Reference-case scenario. In addition, there may be technological innovations which would make it feasible to obtain U_3O_8 from phosphate rock.

Other potential sources of by-product uranium are : copper waste dumps; the red mud obtained when alumina is removed from bauxite; and the beryllium ores of west-central Utah. A modest amount of U_3O_8 is currently obtained from copper produced in Utah and Arizona. DOE estimated, in 1980, [DOE 80] that 500 to 1000 tons of by-product U_3O_8 could be obtained annually from copper ores. Also, DOE estimated that a few hundred short tons per year could be obtained annually from red mud, and that 17 short tons could be obtained from beryllium ores annually, when an already developed plan to recover uranium is employed.

Other Domestic Resources

DOE estimates of the total "endowment" of domestic U_3O_8 resources, are shown in Table 4-20. The "endowment" is defined as all U_3O_8 contained in deposits containing at least .01 percent (100 ppm) of U_3O_8. The resource estimates shown are grouped according to resource category, and by "forward cost of recovery." The three resource categories used by DOE, the primary source for the information contained in Table 4-20, are those used by the International Atomic Energy Commission, and the OECD nuclear power agency:

- Reasonably Assured Resources (RAR): The uranium that occurs in known mineral deposits of such size, grade, and configuration that it could be recovered within the given cost ranges, with currently proven technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. RAR correspond to DOE's Reserve category.

- Estimated Additional Resources (EAR): The uranium in addition to RAR that is expected to occur, mostly on the basis of direct geological evidence, in extension of well-explored deposits, little explored deposits, and undiscovered deposits believed to exist along well-defined geological trends with known deposits, such that the uranium can subsequently be recovered within the given cost ranges. Estimates

Table 4-20: Domestic Uranium Resources Endowment
(thousands of short tons)

Forward Cost of Recovery (Nominal Dollars)	Reasonably Assured Resources	Cumulative	Estimated Additional Resources	Cumulative	Speculative Resources	Cumulative
$ 0 - $ 30 per pound	161	161	675	675	515	515
$ 31 - $ 50 per pound	357	918	510	1,185	460	975
$ 51 - $ 100 per pound	458	815	710	1,895	615	1,590

of tonnage and grade are based on available sampling data and on knowledge of the deposit characteristics, as determined in the best known parts of the deposit or in similar deposits. EAR corresponds to DOE's Provable Potential Resource category.

- Speculative Resources (SR): Uranium in addition to EAR that is thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The locations of deposits in this category can generally be specified only as being somewhere within given regions or geological trends. As the term implies, the existence and size of such deposits are speculative. The estimates in this category are less reliable than estimates of EAR. SR corresponds to DOE's Possible Potential Resources plus Speculative Potential Resource categories.

For each forward cost category of undiscovered resources, the estimates of resources at each cost level are cumulative and include all lower-cost resources within that category.

The "forward cost of recovery" of uranium resources represents estimates of most future costs of mining, processing, and marketing U_3O_8, exclusive of return to capital. These estimates include the costs of transportation, environment and waste management, construction of new operating units, and maintenance of all operating units, future exploration and development costs. Also, appropriate indirect costs such as those for office overhead, taxes and royalties are included. Table 4-20 presents estimates of all U_3O_8 resources having a "forward cost recovery" of no more than $100/lb [DOE 87b].

In addition to estimated U_3O_8 resources in the endowment, there are some large lower grade U_3O_8 resources. The most significant of these are Chattanooga Shale deposits, seawater, and the marine phosphorites from which U_3O_8 is currently obtained as a by-product of phosphoric acid production. It is estimated that the Gassaway Member of Chattanooga Shale is 55 to 70 ppm U_3O_8 and contains about 5 million tons of U_3O_8, as well as larger amounts of vanadium, ammonia, sulfur and oil [MSR 78].

Seawater represents a huge, very low-grade source of uranium, averaging 3 to 4 parts per billion, and containing perhaps five billion tons of U_3O_8. Using very optimistic assumptions, the cost of recovery using current technology has been estimated to be $1400/lb of U_3O_8, albeit, a MIT study suggests that improved technology could reduce the cost to $300/lb, and possibly to $100 or less per pound [CA 79, RO 79].

If, 38,400 short tons of U_3O_8 is produced over the next fourteen years as a result of by-product technology, then given our forecasts (presented earlier for total domestic production) approximately 60,000 short tons of U_3O_8 would have to be obtained from other domestic sources. A relatively insignificant quantity of U_3O_8 could be obtained from existing tailings piles. It has been estimated [DOE 87a] that 127,000 short tons of U_3O_8 could be extracted from mill tailings piles at a forward cost of $100 or less per pound. Hence, the near term scenario indicates that 60,000 tons will be obtained from other domestic sources over the next fourteen years.

Excluding speculative resources, Table 4-20 suggests that there are about 675 thousand short tons U_3O_8 with a forward cost of recovery of no more than $30 per pound. Of these, 161,000 tons are included in the Reasonably Assured Resources category. Given the estimate of total domestic production in Table 4-18 (98,000 tons), it does not appear likely that the price of U_3O_8 will rise above $30 per pound.

4.2.6.2 Total Electricity Generation

Corresponding to the production scenario of domestic U_3O_8 production for the year 2000 are a range of possible projections of total electricity consumption. One end of this range represents the situation in which electricity is produced from conventional fission. (i.e., from U-235) and uranium imports from South Africa and Namibia continue to be restricted. In this situation, perhaps as much as one quarter of all electricity is derived from conventional fission of domestically produced uranium. The percentage of electricity may be lower than this as a result of greater use of electricity from alternative sources, e.g., coal or solar. In constructing our scenarios, we have assumed that there is no technological innovation which would permit either a cessation or a substantial reduction in the construction of new uranium-fueled nuclear power plants. Under various assumptions, the percentage of electricity derived from conventional fission of domestically produced uranium might be as low as two percent, or lower if current technology changes.

A range of projections of total electricity consumption in the year 2000 is presented in Table 4-21. The projections correspond to the previously presented Reference case scenario for total domestic U_3O_8 production under the assumptions that 2, 5, 10 and 25 percent of electricity is derived from

Table 4-21: Projections of Consumption of Electricity from Domestic U-235 in 2000 Under the Reference Case Scenario. (Billions of KWh, net).

Percent of Electricity from Domestic U-235	Domestic U_3O_8 Production Scenario Reference Case
25 %	.932
10 %	2.330
5 %	4.660
2 %	11.650
Approximate Number of 1-GWe Units Supported by Domestic U-235	40

Notes: These projections assume a fixed level of U_3O_8 production, and varying reliance on total demand–since lower the reliance the higher the total production scenario. Further, these projections assume current reactor and enrichment technology.

domestic uranium sources. The projections presume that 31 million KWh (net) of electricity are generated per ton of U_3O_8, [DOE 87d] and, therefore, that there is no significant increase in reactor or enrichment-plant efficiency. If such efficiency improvements occur, the forecasts should be revised upwards.

The projections shown in Table 4-21 suggest that between 0.932 and 11.650 billion KWh of electricity will be produced from domestic sources in the year 2000. The more extreme values in this range, however, represent relatively unlikely combinations of scenarios. These projections assume a fixed level of U_3O_8 production. The most likely projections of consumption of electricity produced from domestic U-235 in the year 2000 are in the 5 and 10 percent range. These forecasts indicate that between 2.33 and 4.66 billion KWh of electricity will be consumed in the year 2000. In addition to the projections of electricity consumption, Table 4-21 also shows the approximate number of 1-GWe nuclear power plant units which would be supported by domestically produced U-235 under the uranium production scenario, assuming a 66 percent average utilization rate. Approximately, 40 units would be supported under the Reference case scenario. It should be noted that a substantial (but undetermined) number of additional units would be supported by imported U-235.

Projected average annual rates of change in electricity are obtained from the forecasts presented in Table 4-21, and from DOE's forecast estimate of 2.46 billion KWh for 1987 [DOE 87e]. The results are presented in Table 4-22. The results range from an average decline of 7.2 percent per year to an average increase of 12.7 percent year. For the most likely scenario, again refer to the values corresponding to the 10 and 5 percent ranges.

It is also possible to express the rates of change in electricity consumption on a per capita basis, using any of several projections of population growth. The U.S. Bureau of Census has recently published data on population forecasts for the U.S. through the year 2080 [BC 84]. According to the forecasts, the U.S. population is assumed to rise from 232 million in 1982 to 267 million in the year 2000. The average annual increase in population over this time period is .784 percent (though the actual rate of increase is initially much higher and declines to zero by the end of the period). Using this population estimate yields the projected average annual rates of change in per capita electricity consumption shown in Table 4-23. These figures are just .784 percent smaller than the corresponding figures shown in Table 4-22, and they range from a 7.98 percent annual decline to

Table 4-22: Average Annual Percentage Change in Electricity Consumption, 1987-2000.

Percent Electricity from Domestic U-235	Domestic U_3O_8 Reference Cast Production Scenario
25 %	- 7.2
10 %	- 0.5
5 %	4.9
2 %	12.7

Table 4-23: Average Annual Percentage Change in Per Capita Electricity Consumption, 1987-2000.

Percent of Electricity from Domestic U-235	Domestic U_3O_8 Reference Case Production Scenario
25 %	- 7.83
10 %	- 1.15
5 %	4.27
2 %	12.07

11.92 percent annual increase. For the most likely scenario, modest average annual decline of 1.20 percent to an average annual increase of 3.87 percent is expected.

4.2.6.3 Employment Projections

Employment projections and historical data for the uranium milling industry are presented in Table 4-24. Forecasts based upon the Reference case scenario show employment growing slowly from 1992 to 1997 after a stagnant, relatively cyclical period from 1987-1991.

The projections are developed in the following manner. Output per person-year is used as a measure of productivity. Data for this variable are obtained by dividing total annual uranium concentrate production from 1967-1986 by each year's total employment in the milling industry, and averaging the results over the 20-year period. The resulting productivity factor of 7.44 short tons per person-year is then divided into the relevant years of the production forecasts summarized in Table 4-18. Average historical productivity is considered suitable for use in projecting future employment because no technological innovations in uranium processing are expected which might affect mill productivity.

4.3 Current Emissions, Risks, and Control Methods

Uranium mills extract uranium from ores which contain only 0.01 to 0.3 percent U_3O_8. The mills are typically located near uranium mines in the western United States in areas of low population density. Since the uranium ores typically contain a low percentage of uranium, virtually all of the ore input to the mill remains as waste which is disposed of in the tailings impoundment. The impoundment areas are formed from dikes built with tailings sands or with soil and rock from the pond area. As the pond is filled, the dikes are raised with mill tailings sands.

During the operating period of the mill, radon releases from the tailings are required to be maintained ALARA. The addition of wet tailings provides a water cover which reduces the radon emissions. The beaches are sprayed to prevent wind erosion and control the radon. At the end of the operating period, the tailings pond is dewatered, and the spraying of water on the beaches is discontinued. This is done so that the tailings can dry sufficiently to provide a stable base for the

Table 4-24: Employment Projections 1987-2000.
Uranium Milling Industry
(person years)

Year	Employment Reference Case
1987	603
1988	635
1989	649
1990	608
1991	570
1992	598
1993	640
1994	668
1995	668
1996	691
1997	696
1998	691
1999	700
2000	696

heavy equipment needed to regrade the impoundment and place the earthen covers required to meet the long-term disposal criteria of the UMTRCA standard.

4.3.1 Current Emissions and Estimated Risk Levels

The evaluation of the risks caused by emissions of radon from licensed conventional uranium mills involves three distinct assessments: the risks that result from the continued use of existing impoundments at the 11 facilities that are operating or on standby; the risks that will occur once all existing piles are disposed of; and the risks that will result from future tailings impoundments. As in the 1986 NESHAPS rulemaking for this source category, the exposures and risks for existing impoundments are assessed on a site-by-site basis, while risks from future impoundments are assessed using model impoundments to represent the alternative technologies. The following sections detail how the radon release rates are developed and identify the sources of the meteorological and demographic data used in the assessment.

4.3.1.1 Methodology for the Assessment of Risks from Operating and Standby Mills

The overall risk from operating and standby mills includes risks resulting from emissions during the operating or standby phase, the drying out and disposal phase, and the post-disposal phase. The following sections detail how the radon release rates were developed for each of these phases to obtain the source terms for the 11 operating and standby mills. The sources of the meteorological and demographic data used in the assessment are also discussed.

Development of the Radon Source Terms

The radon source terms are estimated based on the radon flux rate per unit area and the area of the tailings. This assessment uses the same basic methodology for estimating radon releases and radon source terms that was used in the 1986 NESHAPS rulemaking [EPA86]. For each phase, the methodology involves two estimates: the radon flux per unit area, and the wet and dry areas of the tailings pile.

For both the operating or standby phase and the drying and disposal phase, the radon flux per unit area is calculated on the assumption that 1 $pCi/m^2/sec$ radon-222 is emitted per pCi/g radium-226 in the tailings. This number could be lower because of moisture and other factors, but the conservative value was used since the piles continue to dry out. In the calculations of the specific flux rates, the radium concentrations of the tailings used are those reported in previous studies by the EPA and the NRC [EPA83, NRC80]. For the post-disposal phase, the assumed radon flux per unit area is the design flux of the approved cover, if known, or the 20 pCi/m^2/s (2 pCi/m^2/s for facilities in Colorado) limit established by the regulatory authorities responsible for the implementation of the UMTRCA disposal standard.

Since water and earth covers effectively attenuate radon during the operating or standby phase, the calculated radon flux rate is applied only to the dry area of the operable pile and any associated evaporation ponds. The areas of the wet and dry fractions of the piles have been updated from information obtained during the public comment period. Where new information was not provided, areas are estimated from aerial photographs taken of each pile in 1986.

During the drying and disposal phase the calculated radon flux rates are applied to the total areas of the impoundment and any associated evaporation ponds. For the post-disposal phase, the radon flux is applied only to the area of the impoundment. The areas of any associated evaporation ponds are not included since the radium contamination in these ponds is removed and transferred to the main impoundment prior to stabilization. The total areas of the piles, along with the areas that are estimated to be covered, ponded, wet, or dry, and the radium concentrations in the tailings are shown in Table 4-25.

To obtain the radon source term for each facility, it was necessary to define the duration of each of the three phases. The operating or standby phase is defined to be fifteen years. While it is recognized that some of the impoundments do not have 15 years of capacity remaining at full production, the limited processing that is now occurring makes it possible that these impoundments could remain operational for that length of time. The drying out disposal period is defined to require five years, based on industry and DOE experience to date. Finally, the post-disposal period is defined as fifty years. The sum of the emissions estimated for each period was divided by 70 to obtain the average release per year for input to the assessment codes. The radon source terms calculated for each pile are given in Table 4-26.

Table 4-25. Summary of operable tailings impoundment areas and radium-226 content at operating and standby mills.

State/Impoundment	Surface Area (acres)					Average Ra-226 (pCi/g)
	Total	Covered	Ponded	Wet	Dry	
Colorado						
Canon City - Primary	90	0	88	2	0	400
Canon City - Secondary	40	0	40	0	0	400
Canon City - Total	130	0	128	2	0	400
New Mexico						
Ambrosia Lake - Secondary	121	13	0	0	108	237
Ambrosia Lake - Evap. Ponds	280	0	162	0	118	22
Ambrosia Lake - Total	401	13	162	0	226	87
Homestake - Primary	170	0	100	0	70	300
Homestake - Secondary	40	40	0	0	0	300
Homestake - Total	210	40	100	0	70	300
Texas						
Panna Maria	160	80	40	40	0	198
Utah						
White Mesa	130	0	55	70	5	981
Rio Algom - Lower	47	0	18	29	0	420
Shootaring	7	0	2	1	4	280
Washington						
Sherwood	80	0	0	40	40	200
Wyoming						
Lucky Mc - Pile 1-3	203	108	35	0	60	220
Lucky Mc - Evap. Ponds	104	0	104	0	0	22
Lucky Mc - Total	307	108	139	0	60	153
Shirley Basin	275	0	179	36	60	208
Sweetwater	37	0	30	0	7	280
Totals	1,784	241	853	218	472	--

Table 4-26. Summary of Radon Source Terms Calculated for Operable Mill Tailings Impoundments.

State/Impoundment	Radon Emissions				
	Operating/ Standby Phase (Ci/y)	Drying/ Disposal Phase (Ci/y)	Post-Disposal Phase (Ci/y)	Total Over All Phases (Ci)	Average Over All Phases (Ci/y)
Colorado					
Canon City	0.0E+0	6.6E+3	3.3E+1	3.5E+4	5.0E+2
New Mexico					
Ambrosia Lake	2.5E+3	4.4E+3	9.4E+2	1.1E+5	1.5E+3
Homestake	5.8E+2	8.0E+3	5.4E+2	7.6E+4	1.1E+3
Texas					
Panna Maria	0.0E+0	4.0E+3	4.1E+2	4.1E+4	5.8E+2
Utah					
White Mesa	6.3E+2	1.6E+4	1.2E+2	9.7E+4	1.4E+3
Rio Algom	0.0E+0	5.0E+3	2.4E+2	3.7E+4	5.3E+2
Shootaring	1.4E+2	2.5E+2	1.8E+1	4.3E+3	6.1E+1
Washington					
Sherwood	1.0E+3	2.0E+3	2.0E+2	3.6E+4	5.1E+2
Wyoming					
Lucky Mc	1.2E+3	6.0E+3	5.2E+2	7.3E+4	1.0E+3
Shirley Basin	1.6E+3	7.3E+3	7.0E+2	9.6E+4	1.4E+3
Sweetwater	2.5E+2	1.3E+3	9.5E+1	1.5E+4	2.2E+2

Demographic and Meteorological Data

Site-specific meteorological and demographic data are used in assessing the exposures and risks that result from the release of radon. Demographic data for the nearby individuals (0-5 km) are developed by visits to each site [PNL84]. The results of these surveys for all 26 licensed facilities are shown in Table 4-27. The regional population data were generated using the computer code SECPOP. Meteorological data are from the nearest station. Details of the inputs to the AIRDOS/DARTAB/RADRISK codes are presented in Volume 2 of this *Environmental Impact Statement*.

4.3.1.2 Methodology for the Assessment of Post-Disposal Risks

The UMTRCA rule-making (40 CFR 192) established requirements for the long-term stabilization and disposal of uranium mill tailings. In addition to protection of groundwater and long-term isolation to prevent misuse of tailings, the UMTRCA standards require that the tailings cover be designed to limit the radon flux to a maximum of 20 pCi/m^2/sec. The NRC and the Agreement States, which are responsible for implementing the UMTRCA requirements at licensed facilities, require licensees to demonstrate that the cover designs will achieve the 20 pCi/m^2/s at the end of 1,000 years.

Development of Radon Source Terms

As was done for the assessment of Inactive Tailings (see Chapter 3), the post-disposal source terms for each of the sites was estimated on the basis of the area of the tailings impoundments and the design flux or measured performance of the cover. Where information on the design flux or cover performance was unavailable, the UMTRCA limit of 20 pCi/m^2/s (2 pCi/m^2/s for facilities in Colorado) was used. Table 4-28 summarizes the areas, radon flux rates through the covers, and estimated annual emissions for each of the 26 licensed facilities once disposal is complete.

Source of Demographic and Meteorological Data

The demographic and meteorological data used to assess the post-UMTRCA disposal risks were obtained in the same manner as those used in the assessment risks from operable and standby impoundments. Table 4-27 summarizes the nearby (0-5 km) population around each of the sites.

Table 4-27. Estimated Number of Persons Living Within 5 km of the Centroid of Tailings Impoundments of Licensed Mills.(a)

	Distance (kilometers)						
State/Impoundment	0.0-0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0	Total
Colorado							
Canon City*	0	0	0	184	2,767	2,982	5,933
Uravan*	0	0	0	0	0	0	0
New Mexico							
L-Bar	0	0	0	0	42	124	166
Churchrock*	0	0	18	52	51	150	271
Bluewater*	0	0	0	25	220	294	539
Ambrosia Lake*	0	0	0	0	0	0	0
Homestake*	0	0	187	104	42	57	390
Texas							
Panna Maria	0	12	42	33	81	285	453
Conquista	0	0	3	12	9	18	42
Ray Point	0	0	21	21	30	58	130
Utah							
White Mesa	0	0	0	0	0	8	8
Rio Algom*	0	0	0	0	0	40	40
Moab	0	0	9	33	1,094	1,225	2,361
Shootaring	0	0	0	0	0	171	171
Washington							
Dawn*	0	3	93	157	96	62	411
Sherwood*	0	0	0	0	32	17	49
Wyoming							
Lucky Mc	0	0	0	0	0	0	0
Split Rock*	0	0	0	30	75	40	145
Umetco	0	0	0	0	0	0	0
Bear Creek	0	0	0	0	0	0	0
Shirley Basin	0	0	0	0	0	0	0
Sweetwater	0	0	0	0	0	0	0
Highland	0	0	0	0	6	0	6
FAP	0	0	0	0	0	0	0
Petrotomics	0	0	0	0	96	0	96
Total	0	15	373	651	4,641	5,531	11,211

(a) PNL84, except facilities marked with an asterisk were verified and updated during site visits by SC&A in 1989.

Table 4-28. Summary of Uranium Mill Tailings Impoundment Areas, Flux Rates, and Post-UMTRCA Radon-222 Release Rates.

Owner/Impoundment	Surface Area (acres)	Radon Flux Rate (pCi/m2/s)	Radon-222 Release Rate (Ci/y)
Colorado			
Canon City	130	2	3.3E+1
Uravan	70	2	1.8E+1
New Mexico			
L-Bar	128	20	3.3E+2
Churchrock	100	20	2.6E+2
Bluewater	305	20	7.8E+2
Ambrosia Lake	368	20	9.4E+2
Homestake	210	20	5.4E+2
South Dakota			
Edgemont	123	20	3.1E+2
Texas			
Panna Maria	160	20	4.1E+2
Conquista	240	20	6.1E+2
Ray Point	47	20	1.2E+2
Utah			
White Mesa	130	7	1.2E+2
Rio Algom	93	20	2.4E+2
Moab	147	20	3.8E+2
Shootaring	7	20	1.8E+1
Washington			
Dawn	128	10	1.6E+2
Sherwood	80	20	2.0E+2
Wyoming			
Lucky Mc	220	20	5.2E+2
Split Rock	156	20	4.0E+2
Umetco	218	20	5.6E+2
Bear Creek	90	20	2.3E+2
Shirley Basin	275	20	7.0E+2
Sweetwater	37	20	9.5E+1
Highland	200	20	5.1E+2
FAP	117	20	3.0E+2
Petrotomics	140	20	3.6E+2

4.3.1.3 Methodology for the Assessment of Risks from New Impoundments

A number of alternative control technologies are available for use in new tailings impoundments. Because both timing and disposal method affect the rate of emissions from tailings piles, emissions are estimated for each alternative work practice. A complete description of the various control technologies and the estimated emissions and risks from each are discussed below in Section 4.4.3, Analysis of the Benefits and Costs of Promulgating Future Work Practice Standards.

4.3.1.4 Exposures and Risks from Operating and Standby Mills

Exposures and Risks to Nearby Individuals

The AIRDOS-EPA and DARTAB model codes are used to estimate the increased chance of lung cancer for individuals living near an operable or standby tailings impoundment and receiving the maximum exposure assuming no controls. The results of exposure to the average emissions from all phases, in terms of radon concentration (pCi/l), exposure (WL), and lifetime fatal cancer risk are shown in Table 4-29. Table 4-29 also presents the lifetime fatal cancer risks attributable to the 15 year operating or standby period. The lifetime fatal cancer risks from all phases for individuals residing near these mill sites range from 4E-4 to 5E-6. The lifetime fatal cancer risks to nearby individuals from the operating or standby periods range from 3E-5 to nil, with the highest risk estimated at the Homestake mill in New Mexico. The negligible risks during the operating or standby phase estimated for the Panna Maris, Canon City and La Sal mills result from the fact that the design of these impoundments allows them to be kept totally wet.

Exposures and Risks to the Regional Population

Collective population risks for the region around the mill site are calculated from the annual exposure in person-WLM for the population in the assessment area. Collective exposure calculations expressed in person-WLM are performed for each mill by multiplying the estimated concentration in each annular sector by the population in that sector. Table 4-30 presents the estimated annual regional fatal cancers from operable tailings impoundments for all phases of operations and for the operating or standby phase only.

Table 4-29. Estimated Exposures and Risks to Individuals Living Near Operable Tailings Impoundments With No Contols.

State/Mill	Maximum Radon Concentration (pCi/l)	Maximum Exposure (WL)	Maximum Lifetime Fatal Cancer Risk to Individuals (All Phases)	Maximum Lifetime Fatal Cancer Risk to Individuals (Operations)	Distance(a) (meters)
Colorado					
Canon City	4.2E-3	1.7E-5	2E-5	0E+0	3,500
New Mexico					
Ambrosia Lake	2.7E-3	1.4E-5	2E-5	9E-6	7,500
Homestake	5.8E-2	1.9E-4	3E-4	3E-5	1,500
Texas					
Panna Maria	1.0E-1	3.0E-4	4E-4	0E+0	750
Utah					
White Mesa	2.2E-3	1.5E-5	2E-5	2E-6	25,000
Rio Algom	1.5E-3	6.4E-6	9E-6	0E+0	4,500
Shootaring	8.8E-4	3.8E-6	5E-6	3E-6	4,500
Washington					
Sherwood	4.8E-3	1.9E-5	3E-5	1E-5	3,500
Wyoming					
Lucky Mc	1.2E-3	8.4E-6	1E-5	3E-6	25,000
Shirley Basin	2.2E-3	1.6E-5	2E-5	5E-6	25,000
Sweetwater	6.1E-4	4.2E-6	6E-6	1E-6	25,000

(a) Distance from center of a homogenous circular equivalent impoundment to the point where the exposures and risks were estimated.

Table 4-30. Estimated Fatal Cancers per Year in the Regional (0-80km) Populations around Operable Tailings Impoundments.

State	Mill	Fatal Cancers per Year	
		All Phases	Operating Phase
Colorado	Canon City	6.6E-3	0.0E+0
New Mexico	Ambrosia Lake	3.1E-3	1.5E-3
	Homestake	7.7E-3	8.3E-4
Texas	Panna Maria	1.4E-2	0.0E+0
Utah	White Mesa	1.1E-3	1.1E-4
	Rio Algom	2.8E-4	0.0E+0
	Shootaring	2.2E-5	1.1E-5
Washington	Sherwood	2.9E-3	1.2E-3
Wyoming	Lucky Mc	6.0E-4	1.6E-4
	Shirley Basin	1.8E-3	4.5E-4
	Sweetwater	1.2E-4	3.0E-5
Total		3.9E-2	4.3E-3

Table 4-31. Estimated Distribution of the Fatal Cancer Risk to the Regional (0-80 km) Populations from Operable Uranium Mill Tailings Piles.

Risk Interval	Number of Persons	Deaths/y
1E-1 to 1E+0	0	0
1E-2 to 1E-1	0	0
1E-3 to 1E-2	0	0
1E-4 to 1E-3	230	6E-4
1E-5 to 1E-4	31,000	9E-3
1E-6 to 1E-5	1,000,000	2E-2
< 1E-6	850,000	5E-3
Totals	1,900,000	4E-2

The estimates indicate that these operable impoundments cause 4E-2 deaths/year (4 deaths in 100 years) in the regional (0-80 km) populations in all phases. The emissions from the operating or standby period are estimated to cause 4E-3 deaths/year in the regional population; approximately 10 percent of the risk from all phases of operations.

Distribution of the Fatal Cancer Risk

The frequency distribution of the estimated lifetime fatal cancer risk from all licensed uranium mill tailings under all dry conditions is presented in Table 4-31. This distribution is developed by summing the distributions projected for each of the 11 facilities. The distribution does not account for overlap in the populations exposed to radionuclides released from more than a single mill. Given the remote locations of these facilities and the relatively large distances between mills, this simplification does not significantly understate the lifetime fatal cancer risk to any individual.

4.3.1.5 Post Disposal Exposures and Risks

The exposures and risks that will remain once the impoundments at these 26 licensed sites are disposed of are estimated for the existing UMTRCA disposal design standard of 20 $pCi/m^2/s$ and for alternative fluxes of 6 and 2 $pCi/m^2/s$. As was done for inactive tailings (see Chapter 3), the source terms for each site were calculated based on the lower of the design (or measured flux rate) or the applicable flux standard, and the areas of the impoundments. The estimates for all three alternatives reflect the current demography around these sites.

Exposures and Risks under the UMTRCA Standard

Once all the tailings piles are stabilized and disposed of in accordance with the UMTRCA disposal standard, the radon-222 emission rates will all be at or below $20/pCi/m^2/s$. Estimates of the post-UMTRCA disposal risks to the nearby population are given for the design flux and for alternative fluxes of 6 and 2 $pCi/m^2/sec$ in Table 4-32. Risks to the nearby populations and the estimated distribution of fatal cancer risks are presented for each alternative flux standard in Table 4-33 and Table 4-34, respectively.

Table 4-32. Estimated Exposures and Risks to Nearby Populations Assuming Alternative Flux Rates (a).

State/Site	Distance (b) (meters)	Design Flux			6 pCi/m2/s Limit			2 pCi/m2/s Limit		
		Maximum Radon Concentration (pCi/l)	Maximum Exposure (WL)	Maximum Lifetime Fatal Cancer Risk To Individual	Maximum Radon Concentration (pCi/l)	Maximum Exposure (WL)	Maximum Lifetime Fatal Cancer Risk To Individual	Maximum Radon Concentration (pCi/l)	Maximum Exposure (WL)	Maximum Lifetime Fatal Cancer Risk To Individual
Colorado										
Canon City	3,500	2.8E+04	1.1E-06	2.0E-06	2.8E+04	1.1E-06	2.0E-06	2.8E+04	1.1E-06	2.0E-06
Uraven	7,500	1.3E-04	6.4E+07	9.0E-07	1.3E-04	6.4E+07	9.0E-07	1.3E-04	6.4E+07	9.0E-07
New Mexico										
L-Bar	3,500	6.1E-03	2.4E-05	3.0E-05	1.8E-03	7.2E-06	1.0E-05	6.1E-04	2.4E-06	3.0E-06
Churchrock	1,500	1.2E-02	4.1E-05	6.0E-05	3.6E-03	1.2E-05	2.0E-05	1.2E-03	4.1E-06	6.0E-06
Bluewater	3,500	1.1E-02	4.4E-05	6.0E-05	3.3E-03	1.3E-05	2.0E-05	1.1E-03	4.4E-06	6.0E-06
Ambrosia Lake	7,500	2.3E-03	1.2E-05	2.0E-05	6.9E-03	3.5E-06	5.0E-06	2.3E-04	1.2E-06	2.0E-06
Homestake	1,500	2.9E-02	9.5E-05	1.0E-04	8.5E-03	2.8E-05	4.0E-05	2.7E-03	9.5E-06	1.0E-05
South Dakota										
Edgemont	3,500	2.6E-03	1.0E-05	1.0E-05	7.9E-04	3.2E-06	4.0E-06	2.6E-04	1.0E-06	1.0E-06
Texas										
Panna Maria	750	7.1E-02	2.1E-04	3.0E-04	2.1E-02	6.3E-05	9.0E-05	7.1E-03	2.1E-05	3.0E-05
Conquista	1,500	1.2E-02	3.9E-05	5.0E-05	3.5E-03	1.1E-05	2.0E-05	1.2E-03	3.9E-06	5.0E-06
Ray Point	2,500	3.1E-03	1.1E-05	2.0E-05	9.2E-04	3.4E-06	5.0E-06	3.1E-04	1.1E-06	2.0E-06
Utah										
White Mesa	25,000	1.9E-04	1.3E-06	2.0E-06	1.6E-04	1.1E-06	1.0E-06	5.1E-05	3.6E-07	5.0E-07
Rio Algom	4,500	1.3E-03	5.7E-06	8.0E-06	3.9E-04	1.7E-06	2.0E-06	1.3E-04	5.7E-07	8.0E-07
Moab	2,500	1.6E-02	5.9E-05	8.0E-05	4.7E-03	1.7E-05	2.0E-05	1.6E-03	5.9E-06	8.0E-06
Shootaring	4,500	2.6E-04	1.1E-06	2.0E-06	7.8E-05	3.3E-07	5.0E-07	2.6E-05	1.1E-07	2.0E-07
Washington										
Dawn	750	1.2E-02	3.7E-05	5.0E-05	7.6E-03	2.3E-05	3.0E-05	2.6E-03	7.6E-06	1.0E-05
Sherwood	3,500	1.9E-03	7.4E-06	1.0E-05	5.7E-04	2.3E-06	3.0E-06	1.9E-04	7.4E-07	1.0E-06
Wyoming										
Lucky Mc	25,000	6.3E-04	4.4E-06	6.0E-06	1.9E-04	1.3E-06	2.0E-06	6.3E-05	4.4E-07	6.0E-07
Split Rock	2,500	8.4E-03	3.1E-05	4.0E-05	2.5E-03	9.3E-06	1.0E-05	8.4E-04	3.1E-06	4.0E-06
Umetco	25,000	6.9E-04	4.7E-06	6.0E-06	2.1E-04	1.4E-06	2.0E-06	6.8E-05	4.7E-07	6.0E-07
Bear Creek	15,000	2.8E-04	1.8E-06	2.0E-06	8.4E-05	5.5E-07	7.0E-07	2.8E-05	1.8E-07	2.0E-07
Shirley Basin	25,000	1.1E-03	7.8E-06	1.0E-05	3.3E-04	2.3E-06	3.0E-06	1.1E-04	7.8E-07	1.0E-06
Sweetwater	25,000	2.6E-04	1.8E-06	2.0E-06	7.7E-05	5.4E-07	7.0E-07	2.6E-05	1.8E-07	2.0E-07
Highland	15,000	7.9E-04	5.1E-06	7.0E-06	2.3E-04	1.5E-06	2.0E-06	7.9E-05	5.1E-07	7.0E-07
FAP	15,000	4.1E-04	2.7E-06	4.0E-06	1.2E-04	8.1E-07	1.0E-06	4.1E-05	2.7E-07	4.0E-07
Petrotomics	3,500	3.9E-03	1.6E-05	2.0E-05	1.2E-03	4.9E-06	7.0E-06	3.9E-04	1.6E-06	2.0E-06

(a) Exposures and risks calculated based on lower of the given flux limit and the design flux.

(b) Distance from center of a homogenous circular equivalent impoundment to the point where the exposures and risks were estimated.

Table 4-33. Estimated Fatal Cancers per Year in the Regional (0-80 km) Populations Assuming Alternative Radon Flux Rates (a).

	Design flux	6 pCi/m2/s	2 pCi/m2/s
State/Site	Fatal Cancers per Year	Fatal Cancers per Year	Fatal Cancers per Year
Colorado			
Canon City	4.3E-04	4.3E-04	4.3E-04
Uravan	4.2E-05	4.2E-05	4.2E-05
New Mexico			
L-Bar	4.2E-03	1.2E-03	4.2E-04
Churchrock	1.5E-03	4.4E-04	1.5E-04
Bluewater	4.3E-03	1.3E-03	4.3E-04
Ambrosia Lake	2.7E-03	8.0E-04	2.7E-04
Homestake	3.8E-03	1.1E-03	3.8E-04
South Dakota			
Edgemont	3.7E-04	1.1E-04	3.7E-05
Texas			
Panna Maria	1.0E-02	3.0E-03	1.0E-03
Conquista	1.7E-02	4.9E-03	1.7E-03
Ray Point	5.2E-04	1.7E-04	5.2E-05
Utah			
White Mesa	9.1E-05	7.6E-05	2.5E-05
Rio Algom	2.5E-04	7.6E-05	2.5E-05
Moab	1.3E-03	3.8E-04	1.3E-04
Shootaring	6.5E-06	2.0E-06	6.5E-07
Washington			
Dawn	1.3E-03	8.1E-04	2.7E-04
Sherwood	1.1E-03	3.5E-04	1.1E-04
Wyoming			
Lucky Mc	3.1E-04	1.0E-04	3.1E-05
Split Rock	3.2E-04	9.7E-05	3.2E-05
Umetco	3.3E-04	1.0E-04	3.3E-05
Bear Creek	2.8E-04	8.4E-05	2.8E-05
Shirley Basin	9.2E-04	2.8E-04	9.2E-05
Sweetwater	5.3E-05	1.6E-05	5.3E-05
Highland	6.8E-04	2.0E-04	6.8E-05
FAP	1.9E-04	5.8E-05	1.9E-05
Petrotomics	4.5E-04	1.4E-04	4.5E-05
Total	5.2E-02	1.6E-02	5.8E-03

(a) Fatal cancers per year are calculated based on the lower of the given flux limit and the design flux.

Table 4-34. Estimated Distribution of Fatal Cancer Risk to the Regional (0-80 km) Populations Assuming Alternative Flux Rates.

	Design Flux		6 pCi/m2/s		2 pCi/m2/s	
Risk Interval	Number of Persons	Deaths Per Yr	Number of Persons	Deaths Per Yr	Number of Persons	Deaths Per Yr
1E-1 to 1E+0	0	0	0	0	0	0
1E-2 to 1E+1	0	0	0	0	0	0
1E-3 to 1E+2	0	0	0	0	0	0
1E-4 to 1E+3	75	1E-04	0	0	0	0
1E-5 to 1E+4	28,000	6E-03	520	2E-04	80	2E-05
1E-6 to 1E+5	1,200,000	3E-02	110,000	4E-03	29,000	6E-04
< 1E-6	3,200,000	2E-02	4,400,000	1E-02	4,500,000	5E-03
Totals*	4,500,000	5E-02	4,500,000	2E-02	4,500,000	6E-03

* Totals may not add due to independent rounding.

The estimates show that for nearby individuals the maximum lifetime fatal cancer risk will range from 3E-4 to 9E-7 once disposal activities are completed. The number of deaths/year that will occur in the regional populations around these 26 sites is estimated to be 5E-2 assuming the design flux.

Exposures and Risks under Alternative Disposal Standards

As shown in Tables 4-32 through 4-34, at 6 pCi/m^2/s the maximum individual lifetime fatal cancer risk is 9E-05 at the Panna Maria site, a reduction from 3E-04 under the UMTRCA disposal standard. The estimated deaths per year are reduced from 5E-02 to 2E-02. Similarly, at 2 pCi/m^2/s, the maximum individual risk is reduced by a factor of three to 3E-05, and the deaths/year from all 26 sites is reduced to 6E-3.

4.3.2 Technologies for Long-term Post-disposal Emission Control

Previous studies have examined the feasibility, effectiveness, and cost associated with various options for controlling releases of radioactive materials from uranium mill tailings [NRC80, EPA82, EPA83, EPA86]. These studies have concluded that long-term stabilization and control is required to protect the public from the hazards associated with these tailings. The standards for long term disposal established for these sites under UMTRCA, require controls that prevent misuse of the tailings, protect water resources, and limit releases of radon-222 to the air. The UMTRCA standard established a design standard to limit long-term radon releases to an average flux no greater than 20 pCi/m^2/sec.

Both active and passive controls are available to reduce radon-222 emissions from tailings. Active controls require that some institution, usually a government agency, bear the responsibility for continuing oversight of the piles, and making repairs to the control system when needed. Fencing, warning signs, periodic inspections and repairs, and restrictions on land use are measures that may be used by the oversight agency. Passive controls, on the other hand, are measures of sufficient permanence to require little or no active intervention. Passive controls include measures such as thick earth or rock covers, barriers (dikes) to protect against floods, burial below grade, and moving piles out of flood prone areas, or away from population centers. Of the two methods, active or institutional controls are not preferred for long term stabilization of radon-222 emissions, since institutional performance of oversight duties over a substantial period of time is not reliable.

Previous studies (see above) have identified a number of options to provide long-term control of radon-222 emissions from the tailings. These include earthen or synthetic covers, extraction of radium from the tailings, chemical fixation, and sintering. These long-term control options are discussed in detail in Volume 2 of this *Environmental Impact Statement*.

In comparison to other control technologies earth covers have been shown to be cost-effective [NRC80]. Apart from cost considerations, there are other benefits that accrue by using earth covers as a method to control radon-222 emissions. For example, synthetic covers, such as plastic sheets, do not reduce gamma radiations. However, earth covers that are thick enough to reduce radon-222 emissions will reduce gamma radiation to insignificant levels. Further, chemical and physical stresses over a substantial period of time destabilize synthetic covers, while earthen covers are stable over the long run provided the erosion caused by rain and wind is contained with vegetation and rock covers, and appropriate precautions are taken against natural catastrophes, e.g., floods and earthquakes.

Earthen covers also reduce the likelihood of contaminating ground water that result from either storing radioactive materials in underground mines, (underground mines are typically located under the water table) or by using the leaching process to extract radioactive and non-radioactive contaminants from mill tailings. Moreover, although underground mine disposal is an effective method to protect against degradation and intrusion by man, it nevertheless incurs a social cost. For example, storing tailings in underground mines eliminates the future development of the mines' residual resources. Again, earthen covers with proper vegetation and rock covers can protect against human intrusion, without incurring such social costs.

Finally, earth covers provide more effective long term stabilization than either water or soil cement covers. Albeit, soil cement covers are comparable to earthen covers in terms of cost effectiveness, their long term performance is as yet unknown. Water covers, on the other hand, do not provide the long term stability required for the time periods required, which are at least 1000 years. Moreover, earth covers are more effective stabilizers than water spraying control technology in arid regions.

Covering the dried tailings with dirt is an effective method for reducing radon-222 emissions and is already in use at inactive tailings impoundments. The depth of soil required for a given amount of control varies with the type of earth and radon-222 exhalation rate.

Earth covers decrease radon-222 emissions by retaining radon-222 released from the tailings long enough so that a significant portion will decay in the cover. A rapid decrease in radon-222 emissions is initially achieved by applying almost any type of earth. The high-moisture content earths provide greater radon-222 emission reduction because of their smaller diffusion coefficient.

In practice, earthen cover designs must take into account uncertainties in the measured values of the specific cover materials used, the tailings to be covered, and predicted long-term values of equilibrium moisture content for the specific location. The uncertainty in predicting reductions in radon-222 flux increases rapidly as the required radon-222 emission limit is reduced.

The cost of adding earth covers varies widely with location of the tailings impoundment, its layout, availability of earth, the topography of the disposal site, its surroundings, and hauling distance. Another factor affecting costs of cover material is its ease of excavation. In general, the more difficult the excavation, the more elaborate and expensive the equipment and the higher the cost. The availability of materials such as gravel, dirt, and clay will also affect costs. If the necessary materials are not available locally they must be purchased and/or hauled and costs could increase significantly.

4.4 Analysis of Benefits and Costs

This section presents the benefits and costs of three separate decisions that may be addressed in promulgating the new Clean Air Act standards for release of radionuclides from licensed uranium mill tailings piles. The first decision concerns the limit on allowable radon-222 emissions after closure. Options that are evaluated include reducing radon-222 emissions from the 20 pCi/m^2/sec limit established under UMTRCA to 6 pCi/m^2/sec and 2 pCi/m^2/sec.

The second decision investigates the means by which the emissions from active mills can be reduced to the 20 pCi/m^2/sec limit established under UMTRCA while operations continue. This can be accomplished through the application of earth and water covers to portions of the dry areas of the piles in order to reduce average emissions for the entire site to the 20 pCi/m^2/sec limit.

While the first two decisions are focused on existing piles, the third is concerned with future tailings impoundments. Here alternative work practices for the control of radon emissions from operating mills in the future are evaluated. Options that are investigated include the replacement of the traditional single cell impoundment with phased and continuous disposal impoundments.

This analysis assumes that UMTRCA is in place and that all controls required under UMTRCA will be met regardless of any provisions resulting from this reconsideration of the CAA standards. The beginning point of this analysis (i.e. the baseline) therefore assumes that all controls required by UMTRCA are met, specifically that radon emission levels will be limited to 20 pCi/m^2/sec and that measures will be undertaken to achieve the long-run stability required by the UMTRCA rules.

Benefits are measured as reductions in the estimates of committed cancers resulting from lower allowable emissions. Results are presented in terms of both total benefits and average annual benefits. For the calculation of total benefits a 100-year time period is assumed.

All costs are measured in 1988 dollars and represent the cost of both the disposal and long-term stabilization of the tailings. Cost estimates are calculated assuming no remedial actions have taken place. The costs of meeting the alternative standards are the incremental costs from the baseline (20 pCi/m^2/sec) to the 6 or 2 pCi/m^2/sec alternative. Results are presented in net present value and annualized cost, and are estimated using real interest rates of zero, one percent, five percent and ten percent. As with benefits, a 100-year time period is assumed.

4.4.1 Benefits and Costs of Reducing Post Closure Emissions from 20 pCi/m^2/sec

This section presents the benefits and costs of reducing the allowable radon-222 emissions from the maximum limit of 20 pCi/m^2/sec established under the UMTRCA standard. Options which are evaluated include lowering allowable radon emissions to a maximum of 6 pCi/m^2/sec or a maximum of 2 pCi/m^2/sec.

Although existing impoundments may be in use or on standby with additional available capacity, the control options evaluated in this analysis are based on the simplifying assumption that operations have ceased, that the tailings are sufficiently dry to allow the use of heavy equipment, and that the piles have their current dimensions.

4.4.1.1 Benefits of Reducing the Allowable Limits

It is assumed that reductions in the radon flux rate provided by increasing the depth of cover will yield proportional reductions in committed cancers. The resulting estimates of committed cancers per year on a pile-by-pile basis are presented above for the 20, 6 and 2 pCi/m^2/sec options in Table 4-35.

Table 4-35 summarizes the estimates of risk and reduction of risk (committed cancers) for the various regulatory options. The table presents these estimates for the 100 year period as well as annual averages. Over the 100 year time frame the 6 pCi/m^2/sec option lowers local and regional risks by 3.6 committed cancers. The incremental benefit of lowering the allowable flux rate from 6 pCi/m^2/sec to 2 pCi/m^2/sec is estimated as 1.0 committed cancer.

4.4.1.2 Costs of Reducing the Allowable Limits

For reasons described above, the supplemental control selected for long-term radon-222 control at existing tailings impoundments is the earth cover control option. The thickness of cover required to achieve a given radon flux is a function of the initial radon flux from the pile. Five basic steps or operations are required to implement the supplemental controls for existing tailings piles. These include regrading slopes, procurement and placing of the dirt cover, placing gravel on the pile tops, placing of rip-rap on the pile sides, and reclamation of the borrow pits. The estimation of earth cover thicknesses and the costs for the five operations are described in detail in Appendix B of Volume 2 of this *Environmental Impact Statement*.

In order to properly reflect general industry overhead and costs, an overhead cost factor of 1.07 is used to adjust the cost of earth cover described above, (see Appendix B, Volume 2 for a discussion of cost factors). Estimates of costs, with and without the overhead cost factor, are presented for each pile for the 20, 6 and 2 pCi/m^2/sec options in Tables 4-36, 4-37, and 4-38, respectively. Achieving the 20 pCi/m^2/sec option is estimated to cost between $560 to $599 million. In contrast, reaching the 6 pCi/m^2/sec option is estimated to cost from $728 to $779 million while compliance with the 2 pCi/m^2/sec option would entail costs estimated to reach between $882 to $943 million.

Table 4-39 provides the incremental present value costs for the two radon fluxes and added costs for lowering the allowable flux. Estimates for each of the four real interest rates are included assuming an overhead cost factor of 1.07. Reducing the allowable flux rate to 6 pCi/m^2/sec will entail added present value costs of between $113 and $180 million depending on assumptions as to real interest rates, while attainment of a 2 pCi/m^2/sec flux rate would entail added costs of $216 to

Table 4-35: Total and Annualized Risk and Reduction of Risk (Committed Cancers over 100 years) of Lowering the Allowable Flux limit to 6 and 2 pCi/m2/sec.

	20 pdCi/m2/sec Baseline	6 pCi/m2/sec Option		2 pCi/m2/sec Option		
	Risk	Risk	Risk Reduction from 20 pCi/m2/sec Baseline	Risk	Risk Reduction from 20 pCi/m2/sec Baseline	Risk Reduction from 6 pCi/m2/sec Baseline
Risk	5.20	1.60		0.58		
Cancers avoided over 100 years:			3.60		4.62	1.02
Risk	0.052	0.016		0.0058		
Annual cancers avoided:			0.036		0.046	0.010

Table 4-36: Costs of Achieving the 20 pCi/m2/sec Option for Licensed Mills (1988 $, Millions) (a).

Mill/Pile	Excavate Evap. Ponds	Regrade Slopes	Dirt Cover	Apply Riprap	Apply Gravel	Reclaim Borrow Pits	Total	Total Inc. O&P @ 7%
Canon City								
Primary	0.00	0.78	9.22	1.69	0.83	0.45	12.96	13.87
Secondary	0.00	0.23	4.10	0.75	0.37	0.20	5.65	6.04
Uravan	0.00	0.53	7.61	1.31	0.65	0.37	10.47	11.20
L Bar	0.00	1.31	14.09	2.40	1.18	0.69	19.67	21.05
Churchrock	0.00	0.91	9.14	1.87	0.92	0.45	13.30	14.23
Bluewater	0.00	4.84	30.43	5.71	2.82	1.48	45.29	48.46
Ambrosia Lake								
Primary	0.00	3.52	27.24	4.63	2.28	1.33	39.00	41.73
Secondary	0.00	1.21	10.23	2.27	1.12	0.50	15.32	16.40
Lined Ponds	8.90	0.00	0.00	0.00	0.00	0.00	8.90	9.53
Unlined Ponds	4.20	0.00	0.00	0.00	0.00	0.00	4.20	4.49
Homestake								
Primary	0.00	2.01	15.74	3.18	1.57	0.77	23.28	24.91
Secondary	0.00	0.23	3.70	0.75	0.37	0.18	5.23	5.60
Edgemont	0.00	1.24	14.02	2.30	1.14	0.68	19.38	20.74
Panna Maria	0.00	1.84	12.54	3.00	1.48	0.61	19.47	20.83
Conquista	0.00	3.38	19.83	4.50	2.22	0.97	30.89	33.05
Ray Point	0.00	0.29	5.24	0.88	0.43	0.26	7.10	7.60
White Mesa	0.00	1.35	17.31	2.43	1.20	0.84	23.13	24.75
Rio Algom								
Upper	0.00	0.28	4.79	0.86	0.43	0.23	6.59	7.05
Lower	0.00	0.29	4.89	0.88	0.43	0.24	6.74	7.21
Moab	0.00	1.62	16.57	2.75	1.36	0.81	23.11	24.72
Shootaring	0.00	0.02	0.63	0.13	0.06	0.03	0.88	0.94
Dawn	0.00	1.31	10.88	2.40	1.18	0.53	16.30	17.44
Sherwood	0.00	0.65	6.30	1.50	0.74	0.31	9.49	10.16
Lucky Mac								
Piles 1-3	0.00	2.63	16.65	3.80	1.88	0.81	25.76	27.57
Evap. Ponds	3.31	0.00	0.00	0.00	0.00	0.00	3.31	3.54
Split Rock	0.00	1.77	8.59	2.92	1.44	0.42	15.14	16.20
UMETCO GH	0.00	2.92	21.43	4.08	2.02	1.06	31.71	33.93
Bear Creek	0.00	0.78	4.65	1.69	0.83	0.22	7.96	8.52
Shirley Basin	0.00	4.14	22.02	5.15	2.54	1.07	34.93	37.38
Sweetwater	0.00	0.20	3.34	0.69	0.34	0.16	4.74	5.07
Highland	0.00	2.57	21.29	3.75	1.85	1.04	30.50	32.63
FAP	0.00	1.15	12.18	2.19	1.08	0.59	17.20	18.40
Petrotomics	0.00	1.50	16.04	2.62	1.29	0.78	22.24	23.80
Totals	16.41	45.49	370.69	73.09	36.09	18.08	559.84	599.02

(a) Costs are Calculated for the lower of the given flux rate or the design flux.

Table 4-37: Costs of Achieving the 6 pCi/m2/sec Option for Licensed Mills (1988 $, Millions) (a).

Mill/Pile	Excavate Evap. Ponds	Regrade Slopes	Dirt Cover	Apply Riprap	Apply Gravel	Reclaim Borrow Pits	Total	Total Inc. O&P @ 7%
Canon City								
Primary	0.00	0.78	12.93	1.69	0.83	0.63	16.85	18.03
Secondary	0.00	0.23	5.74	0.75	0.37	0.28	7.37	7.89
Uravan	0.00	0.53	10.49	1.31	0.65	0.51	13.49	14.44
L Bar	0.00	1.31	19.36	2.40	1.18	0.94	25.20	26.96
Churchrock	0.00	0.91	13.26	1.87	0.92	0.65	17.61	18.85
Bluewater	0.00	4.84	42.99	5.71	2.82	2.10	58.46	62.55
Ambrosia Lake								
Primary	0.00	3.52	37.41	4.63	2.28	1.82	49.67	53.14
Secondary	0.00	1.21	15.21	2.27	1.12	0.74	20.55	21.99
Lined Ponds	8.90	0.00	0.00	0.00	0.00	0.00	8.90	9.53
Unlined Pond	4.20	0.00	0.00	0.00	0.00	0.00	4.20	4.49
Homestake								
Primary	0.00	2.01	22.74	3.18	1.57	1.11	30.62	32.76
Secondary	0.00	0.23	5.35	0.75	0.37	0.26	6.96	7.45
Edgemont	0.00	1.24	19.08	2.30	1.14	0.93	24.69	26.42
Panna Maria	0.00	1.84	19.13	3.00	1.48	0.93	26.38	28.22
Conquista	0.00	3.38	29.71	4.50	2.22	1.45	41.25	44.14
Ray Point	0.00	0.29	7.17	0.88	0.43	0.35	9.13	9.77
White Mesa	0.00	1.35	22.66	2.43	1.20	1.11	28.75	30.76
Rio Algom								
Upper	0.00	0.28	6.68	0.86	0.43	0.33	8.58	9.18
Lower	0.00	0.29	6.83	0.88	0.43	0.33	8.77	9.38
Moab	0.00	1.62	22.62	2.75	1.36	1.10	29.45	31.52
Shootaring	0.00	0.02	0.92	0.13	0.06	0.04	1.18	1.26
Dawn	0.00	1.31	16.15	2.40	1.18	0.79	21.83	23.36
Sherwood	0.00	0.65	9.59	1.50	0.74	0.47	12.95	13.86
Lucky Mc								
Piles 1-3	0.00	2.63	25.00	3.80	1.88	1.22	34.53	36.95
Evap. Ponds	3.31	0.00	0.00	0.00	0.00	0.00	3.31	3.54
Split Rock	0.00	1.77	15.01	2.92	1.44	0.73	21.87	23.41
UMETCO GH	0.00	2.92	30.61	4.08	2.02	1.49	41.12	44.00
Bear Creek	0.00	0.78	8.16	1.69	0.83	0.40	11.85	12.68
Shirley Basin	0.00	4.14	33.35	5.15	2.54	1.63	46.81	50.08
Sweetwater	0.00	0.20	4.86	0.69	0.34	0.24	6.34	6.78
Highland	0.00	2.57	29.53	3.75	1.85	1.44	39.13	41.87
FAP	0.00	1.15	17.00	2.19	1.08	0.83	22.25	23.81
Petrotomics	0.00	1.50	21.80	2.62	1.29	1.06	28.29	30.27
Totals	16.41	45.49	531.34	73.09	36.09	25.92	728.33	779.31

(a) Costs are calculated for the lower of the given flux rate and the design flux.

Table 4-38: Costs of Achieving the 2 pCi/m2/sec Option for Licensed Mills (1988 $, Millions) (a).

Mill/Pile	Excavate Evap. Ponds	Regrade Slopes	Dirt Cover	Apply Riprap	Apply Gravel	Reclaim Borrow Pits	Total	Total Inc. O&P @ 7%
Canon City								
Primary	0.00	0.78	16.31	1.69	0.83	0.80	20.40	21.82
Secondary	0.00	0.23	7.25	0.75	0.37	0.35	8.95	9.58
Uravan	0.00	0.53	13.12	1.31	0.65	0.64	16.25	17.39
L Bar	0.00	1.31	24.17	2.40	1.18	1.18	30.24	32.36
Churchrock	0.00	0.91	17.02	1.87	0.92	0.83	21.55	23.06
Bluewater	0.00	4.84	54.45	5.71	2.82	2.66	70.47	75.41
Ambrosia Lake								
Primary	0.00	3.52	46.69	4.63	2.28	2.28	59.40	63.56
Secondary	0.00	1.21	19.76	2.27	1.12	0.96	25.32	27.09
Lined Ponds	8.90	0.00	0.00	0.00	0.00	0.00	8.90	9.53
Unlined Pond	4.20	0.00	0.00	0.00	0.00	0.00	4.20	4.49
Homestake								
Primary	0.00	2.01	29.13	3.18	1.57	1.42	37.32	39.93
Secondary	0.00	0.23	6.85	0.75	0.37	0.33	8.54	9.13
Edgemont	0.00	1.24	23.70	2.30	1.14	1.16	29.54	31.60
Panna Maria	0.00	1.84	25.14	3.00	1.48	1.23	32.68	34.97
Conquista	0.00	3.38	38.73	4.50	2.22	1.89	50.71	54.25
Ray Point	0.00	0.29	8.94	0.88	0.43	0.44	10.98	11.75
White Mesa	0.00	1.35	27.54	2.43	1.20	1.34	33.87	36.24
Rio Algom								
Upper	0.00	0.28	8.41	0.86	0.43	0.41	10.39	11.12
Lower	0.00	0.29	8.59	0.88	0.43	0.42	10.62	11.36
Moab	0.00	1.62	28.14	2.75	1.36	1.37	35.25	37.71
Shootaring	0.00	0.02	1.18	0.13	0.06	0.06	1.45	1.56
Dawn	0.00	1.31	[illegible]0.96	2.40	1.18	1.02	26.87	28.76
Sherwood	0.00	0.65	12.60	1.50	0.74	0.61	16.10	17.23
Lucky Mc								
Piles 1-3	0.00	2.63	32.63	3.80	1.88	1.59	42.53	45.50
Evap. Ponds	3.31	0.00	0.00	0.00	0.00	0.00	3.31	3.54
Split Rock	0.00	1.77	20.87	2.92	1.44	1.02	28.02	29.98
UMETCO GH	0.00	2.92	38.80	4.08	2.02	1.89	49.71	53.19
Bear Creek	0.00	0.78	11.54	1.69	0.83	0.56	15.40	16.47
Shirley Basin	0.00	4.14	43.68	5.15	2.54	2.13	57.64	61.68
Sweetwater	0.00	0.20	6.25	0.69	0.34	0.30	7.80	8.34
Highland	0.00	2.57	37.04	3.75	1.85	1.81	47.01	50.30
FAP	0.00	1.15	21.39	2.19	1.08	1.04	26.86	28.74
Petrotomics	0.00	1.50	27.06	2.62	1.29	1.32	33.80	36.17
Totals	16.41	45.49	677.94	73.09	36.09	33.07	882.07	943.82

(a) Costs are calculated for the lower of the given flux rate or the design flux.

Table 4-39: Incremental Present Value Costs of Lowering the Allowable Limit to 6 pCi/m2/sec and 2 pCi/m2/sec at Licensed Mills. (1988 $, Millions)

	6 pCi/m2/sec Option	2 pCi/m2/sec Option	
	Incremental Cost From 20 pCi/m2/sec Baseline	Incremental Cost From 20 pCi/m2/sec Baseline	Incremental Cost From 6 pCi/m2/sec Option
0 % Real Interest Rate	$180.28	$344.79	$164.51
1 % Real Interest Rate	$171.55	$328.09	$156.54
5 % Real Interest Rate	$141.59	$270.80	$129.20
10 % Real Interest Rate	$112.96	$216.04	$103.08

$345 million. The added costs of reducing the allowable limit from 6 pCi/m^2/sec to 2 pCi/m^2/sec ranges between $103 million and $165 million.

Table 4-40 provides similar estimates to those given in Table 4-39 except the values in 4-40 are presented on an annualized cost basis. For the 6 pCi/m^2/sec option, added costs on an annualized basis range from $9 to $13 million depending on discount rate assumptions. For the 2 pCi/m^2/sec option, added costs vary from $17 to $25 million. The added annualized cost of reducing the allowable limit from 6 pCi/m^2/sec to 2 pCi/m^2/sec ranges between $8 to $12 million.

4.4.2 Benefits and Costs of Reducing Allowable Emissions During Operation

This section presents the benefits and costs of reducing radon-222 emissions to the 20 pCi/m^2/sec UMTRCA limit without curtailing the operation of the tailings impoundments. As in the preceding analysis, benefits are measured in terms of maximum exposure and maximum lifetime fatal cancer risks both to nearby and regional (0-80km) populations.

Costs are measured in nominal 1988 dollars, and represent the incremental change in costs associated with the cost of water and earth cover needed to achieve the 20 pCi/m^2/sec standard. Results are given using net present values, and are also annualized using real rates of interest of 0, 1, 5 and 10 percent. A 100-year time period is also used in generating these estimates.

4.4.2.1 Methods of Reducing Average Emissions to 20 pCi/m^2/sec

In this analysis, it is assumed that average radon emissions can be reduced through the saturation of some portion of the dry areas of the tailings piles without interfering with the operation of the mills. The area that must be saturated depends upon the proportion of the pile that is currently dry, and thus currently emitting radon, and the average radium content of the pile. In cases where the tailings pile is unlined, it is assumed that a dirt cover is applied before the area is saturated, to protect groundwater from contamination. A dirt cover that would reduce emissions to 20 pCi/m^2/sec is considered sufficient to prevent the contamination of ground water once the area is saturated. In instances where piles are lined, the application of earth cover is not necessary as the liner will protect the ground water from contamination.

Table 4-40: Incremental Annualized Costs of Lowering the Allowable Limit to 6 pCi/m2/sec and 2 pCi/m2/sec at Licensed Mills. (1988 $, Millions)

	6 pCi/m2/sec Option	2 pCi/m2/sec Option	
	Incremental Cost From 20 pCi/m2/sec Baseline	Incremental Cost From 20 pCi/m2/sec Baseline	Incremental Cost From 6 pCi/m2/sec Option
0 % Real Interest Rate	$9.01	$17.24	$8.23
1 % Real Interest Rate	$9.51	$18.18	$8.67
5 % Real Interest Rate	$11.36	$21.73	$10.37
10 % Real Interest Rate	$13.27	$25.38	$12.11

In this analysis, no emissions are assumed for the ponded and wet areas of the piles, while the dry areas are assumed emit radon-222 at the rate of 1 pCi/m^2/sec for a concentration of 1 pCi/g of Ra-226 found in the tailings. All covered areas are assumed to emit radon at the rate of 20 pCi/m^2/sec. Table 4-42A, on page 4-78, reproduces the summary of operable tailings impoundment areas presented in Table 4-25, along with the average flux rates of the piles, and the areas of the piles that must be covered and/or saturated in order to reduce average emissions to the 20 pCi/m^2/sec limit.

4.4.2.2 Benefits of Reducing Allowable Flux Limit to 20 pCi/m^2/sec

The benefits of reducing alowable emissions during operations to 20 pCi/m^2/sec are presented, both in terms of reductions in maximum individual risk and in cancer deaths per year, for each site in Table 4-41. The risks for the 20 pCi/m2/sec are the risks presented for the post-closure option adjusted to represent the fifteen year operating or standby phase. The largest reduction in cancer deaths was for the White Mesa plant in Utah at 1.1E-02 and 1.6E-1 cancer deaths per year and for the 15 year operating period, respectively. Because design factors at the Panna Maria, Canon City, and La Sal mills allow the tailing to be kept totally wet, risks remain negligible for the entire operating and standby phase.

4.4.2.3 Costs of Reducing Allowable Flux Limit to 20 pCi/m2/sec

Costs resulting from the reduction of allowable emissions to meet the UMTRCA standard are of two basic types. First, where the dry areas of the pile are unlined, an earth cover must be applied before the area can be saturated. This is primarily to prevent contamination of underground water resulting from absorption into the earth beneath the tailings, and is incurred only in the first year of the operation. The second cost, the cost of the water used in the saturation process, is incurred annually over the active life of the mill site. These costs are discussed in detail below.

Water Cost

In order to effectively attenuate the release of radon from the saturated areas, a constant moisture level must be maintaind on the tailings surfaces. Thus, water must be added to the piles to compensate for evaporation, with the amount required dependent upon the area to be kept moist and regional evaporation rates. An estimate of the amount of water needed has been calculated for each site and is presented in appendix A to this chapter.

Table 6-47. Risks and Reduction of Risks for Continued Operations at 20 pCi/m2/sec (a).

State/Mill	Lifetime Fatal Cancer Risk to Individuals (Current)	Lifetime Fatal Cancer Risk to Individuals (20 pCi/m2/sec)	Fatal Cancers Per Year (Current)	Fatal Cancers Per Year (20 pCi/m2/sec)	Reductions in Fatal Cancer Risk to Individuals	Reductions in Fatal Cancers Per Year	Reductions in Fatal Cancers Over 15 Years
Colorado							
Canon City*	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
New Mexico							
Ambrosia Lake	9.0E-06	4.3E-06	1.5E-03	1.5E-03	4.7E-06	0.0E+00	0.0E+00
Homestake	3.0E-05	2.1E-05	8.3E-04	8.3E-04	8.6E-06	0.0E+00	0.0E+00
Texas							
Panna Maria*	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Utah							
White Mesa	2.0E-06	4.3E-07	1.1E-02	9.1E-05	1.6E-06	1.1E-02	1.6E-01
Rio Algom*	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Shootaring	3.0E-06	4.3E-07	1.1E-05	6.5E-06	2.6E-06	4.5E-06	6.8E-05
Washington							
Sherwood	1.0E-05	2.1E-06	1.2E-03	1.1E-03	7.9E-06	1.0E-04	1.5E-03
Wyoming							
Lucky Mc	3.0E-06	1.3E-06	1.6E-04	1.6E-04	1.7E-06	0.0E+00	0.0E+00
Shirley Basin	5.0E-06	2.1E-06	4.5E-04	4.5E-04	2.9E-06	0.0E+00	0.0E+00
Sweetwater	1.0E-06	4.3E-07	3.0E-05	3.0E-05	5.7E-07	0.0E+00	0.0E+00
Total	6.3E-05	3.3E-05	1.5E-02	4.2E-03	3.0E-05	1.1E-02	1.7E-01

(a) Risks and reduction of risks are calculated for 15 year operation and standby phase only.
* Design of mill allows for tailings to be kept totally wet during operations.

Generally, water can be pumped by the mill companies from underwater sources or from nearby rivers to which the mills have access and water rights. Hence, the cost of the water to the mills is the cost of the energy needed to operate the pumping facility. These costs are based on the area to be saturated, evaporation rates, the vertical distance water must be lifted, and local industrial rates for electric power. These data and the calculations of the costs are also presented in Appendix A to this chapter. The annual cost of water is presented for each plant in Table 42B.

Earth Cost

In cases where the dry areas of the piles are unlined, an earth cover must be applied prior to saturation to prevent ground water contamination. The amount of earth cover required depends upon the size of the area to be saturated and whether the area to be saturated is protected by a liner. The cost of earth cover is estimated in the same manner as in the section dealing with the cost of achieving the post-closure 20 pCi/m2/sec option (Table 4-36), with the exception that only the cost of regrading slopes, applying dirt cover, and reclaiming borrow pits are considered. The cost of earth cover is presented for each plant in Table 42B. In addition, Table 42B contains the present value total cost (earth and water), and annualized present value total cost for each mill and for all mills combined.

4.4.3 Analysis of Benefits and Costs of Promulgating Future Work Practice Standards

This section presents the benefits and costs of using alternative control technologies for future tailings piles. The alternative methods of disposal of radioactive tailings are compared to the base case control technology of the single cell design. Benefits are measured in terms of the incremental change in committed fatal cancers, presented in terms of both total and annual averages. A 100 year time frame is used to calculate total benefits.

Costs are measured in nominal 1988 dollars, and represent the incremental change in costs associated with the disposal and stabilization of mill tailings. Results are given using net present values, and are also annualized using real rates of interest of 0, 1, 5 and 10 percent. A 100-year time period is also used in generating these estimates.

Table 6-42b. Earth and Water Cover Required to Achieve Emissions of 20 pCi/m2/sec.

State/Mill	Liner Type (a)	Surface Area (acres) Wet	Covered	Ponded	Dry Area	Dry Flux(b) (pCi/m2/sec)	Total	Average Flux Rate All Areas (pCi/m2/sec)	Total Area To be Saturated (c) (Acres)	Area to be Covered and Saturated (Acres)
Colorado										
Cannon City	SL	2	0	128	0	0	130	0	0	0
Primary		2	0	88	0		90			
Secondary		0	0	40	0		40			
New Mexico										
Ambrosia Lake	UL	0	13	162	226	87	401	49.03	146.82	15.82
Secondary		0	13	121	108		242			
Evap. Ponds		0	0	162	118		280			
Homestake	UL	0	40	100	70	300	210	100.00	96.00	56
Primary		0	0	100	70		170			
Secondary		0	40	0	0		40			
Texas										
Panna Maria	NC	40	80	40	0	0	160	<20	0	0
Utah										
White Mesa	SL	70	0	55	5	981	130	37.73	2.35	0
Rio Algom	NC	29	0	18	0	0	47	0	0	0
Shootaring	UL	1	0	2	4	280	7	160.00	3.50	3.5
Washington										
Sherwood	SL	40	0	0	40	200	80	100.00	32.00	0
Wyoming										
Lucky Mc		0	108	139	60	153	307	29.90	127.87	19.87
Pile 1-3	UL	0	108	35	60		203			
Evap. Ponds		0	0	104	0		104			
Shirley Basin	UL	36	0	179	60	208	275	45.38	33.56	33.56
Sweetwater	SL	0	0	30	7	280	37	52.97	4.36	0
Total		218	241	853	472		1,784		446.45	128.75

(a) SL = Synthetic Liner, NC = Clay Liner, UL = Unlined.

(c) Where piles contain dry ponds, lined ponds are saturated before unlined areas are considered for treatment.

Table 4-42B Cost of Earth Cover and Water Required to Achieve Average Emissions of 20 pCi/m2/sec.

State/Mill	Liner Type (a)	Total Area To be Saturated (Acres)	Area to be Covered and Saturated (Acres)	Cost of Earth Cover(b) ($1,000)	Annual Water Cost ($1,000)	Present Value Cost (15 Year Period) ($1,000) 0%	1%	5%	10%	Annualized Cost (15 Year Period) ($1,000) 0%	1%	5%	10%
Colorado													
Canon City	SL	0.0	0.0	0	0	$0	$0	$0	$0	$0.0	$0.0	$0.0	$0.0
New Mexico													
Ambrosia Lake	UL	146.8	15.8	$1,737	$22	$2,061	$2,020	$1,879	$1,744	$137.4	$145.7	$181.0	$229.2
Homestake	UL	96.0	56.0	$6,035	$55	$6,866	$6,743	$6,323	$5,908	$457.7	$486.4	$609.1	$776.7
Texas													
Panna Maria	WC	0.0	0.0	$0	$0	$0	$0	$0	$0	$0.0	$0.0	$0.0	$0.0
Utah													
White Mesa	SL	2.3	0.0	$0	$1	$14	$13	$9	$7	$0.9	$0.9	$0.9	$0.9
Rio Algom	WC	0.0	0.0	$0	$0								
Shootaring	UL	3.5	3.5	$9	$1	$26	$24	$20	$16	$1.7	$1.8	$1.9	$2.2
Washington													
Sherwood	SL	32.0	0.0	$0	$0	$0	$0	$0	$0	$0.0	$0.0	$0.0	$0.0
Wyoming													
Lucky Mc	UL	127.9	19.9	$1	$45	$676	$625	$468	$343	$45.1	$45.1	$45.1	$45.2
Shirley Basin	UL	33.6	33.6	$3,323	$12	$3,500	$3,454	$3,287	$3,111	$233.3	$249.1	$316.7	$409.0
Sweetwater	SL	4.4	0.0	NA	$2	$23	$21	$16	$12	$1.5	$1.5	$1.5	$1.5
Total		446.4	128.8	$11,105	$137	$13,166	$12,900	$12,002	$11,141	$878	$930	$1,156	$1,465

(a) SL = Synthetic Liner, WC = Clay Liner, UL = Unlined.

(b) Total cost of regrading slopes, applying dirt cover and reclaiming borrow pits for portion of site requiring dirt cover.

4.4.3.1 Work Practices for New Tailings Impoundments

Tailings impoundments constructed in the future must, at minimum, meet current Federal standards for prevention of groundwater contamination and airborne particulate emissions (20 pCi/m^2/sec). The baseline tailings impoundment will have synthetic liners, be built partially below grade and have earthen dams or embankments to facilitate decommissioning. A means for dewatering the tailings after the area is filled should also be incorporated. This conventional design allows the maintenance of a water cover during the milling and standby periods thus maintaining a very low level of radon-222 emissions. Dewatering of the tailings can be accelerated using wells and/or built-ins. A synthetic liner is placed along the sides and bottom. Cover material may be added after the impoundment has reached capacity or is not going to be used further and the tailings have dried. Two alternatives to the work practices assumed in this baseline model of new tailings impoundments are evaluated in this analysis. These alternatives are discussed in the following sections.

Phased Disposal

The first alternative work practice which is evaluated for model new tailings impoundments is phased disposal. In phased or multiple cell disposal, the tailings impoundment area is partitioned into cells which are used independently of other cells. After a cell has been filled, it can be dewatered and covered, and another cell used. Tailings are pumped to one initial cell until it is full. Tailings are then pumped to a newly constructed second cell and the former cell is dewatered and then left to dry. After the first cell drys, it is covered with earth obtained from the construction of a third cell. This process is continued sequentially. This system minimizes emissions at any given time since a cell can be covered after use without interfering with operations as opposed to the case of a single cell.

Phased disposal is effective in reducing radon-222 emissions since tailings are initially covered with water and finally with earth. Only during a drying-out period of about 5 years for each cell are there any radon-222 emissions from a relatively small area. During mill standby periods, a water cover could be maintained on the operational cell. For extended standby periods, the cell could be dewatered and a dirt cover applied.

Continuous Disposal

The second alternative work practice, continuous disposal, is based on the fact that water can be removed from the tailings slurry prior to disposal. The relatively dry dewatered (25 to 30% moisture) tailings can then be dumped and covered with soil almost immediately. No extended drying phase is required, and therefore very little additional work would be required during final closure. Additionally, ground water problems are minimized.

To implement a dewatering system would introduce complications in terms of planning, design, and modification of current designs. Acid-based leaching processes do not generally recycle water, and additional holding ponds with ancillary piping and pumping systems would be required to handle the liquid removed from the tailings. Using trucks or conveyor systems to transport the tailings to disposal areas might also be more costly than slurry pumping. Thus, although tailings are more easily managed after dewatering, this practice would have to be carefully considered on a site-specific basis.

Various filtering systems such as rotary vacuum and belt filters are available and could be adapted to a tailings dewatering system. Experimental studies would probably be required for a specific ore to determine the filter media and dewatering properties of the sand and slime fractions. Modifications to the typical mill ore grinding circuit may be required to allow efficient dewatering and to prevent filter plugging or blinding. Corrosion-resistant materials would be required in any tailings dewatering system due to the highly corrosive solutions which must be handled. Continuous covering of dewatered tailings is not practiced at any uranium mills in the United States, but it has been proposed at several sites in the Southwestern and Eastern United States [MA 83]. Tailings dewatering systems have been used successfully at nonferrous ore beneficiation mills in the United States and Canada [RO 78].

4.4.3.2 Comparison of Control Technologies for New Tailings Impoundments.

To meet current Federal radon-222 emission standards, new tailings areas will have synthetic liners with either earthen dams or embankments, and also incorporate a means of dewatering the tailings at final closure. These new tailings can either be stored below or partially above grade. Although, below grade storage provides the maximum protection from windblown emissions, water erosion, and eliminates the potential for dam failure, it nevertheless is not cost effective in comparison to partially above grade disposal technology.

Previous analysis of work practices for new model tailings have estimated costs for a range of alternative control technologies [EPA 86]. These estimated costs,in millions of 1985 dollars, are listed in Table 4-43. These cost estimates suggest that storage of tailings partially above grade is cost effective in comparison to fully below grade designs. Completely below grade designs are estimated, on average, to increase costs by twenty percent.

Partially below grade piles have been shown to be cost effective compared to above grade impoundments. Excavation costs for the final dirt cover are incurred in both cases. Using the excavated pit, from which the earth cover is taken, to store tailings provides benefits in terms of windblown emissions, water erosion, and dam failure at no cost. In addition, dam construction cost is minimized because the sides of the excavation pit replace part of the dam.

The twenty percent increase in costs over partially above grade disposal are not justified by the benefits gained from completely below grade disposal. As prior excavation has provided all the dirt required for cover, the increase in costs associated with further excavation to fully below grade are not believed to justify the associated benefits. The cost of additional excavation is greater than the benefit as the bulk of the benefits to be derived from reducing windblown emissions, water erosion, and dam failure have already been captured. For our purposes, therefore, only designs that are partially above grade are considered.

Also dropped from consideration is the continuous trench pile design. This technology has little operational advantage over the continuous single cell design, and is more costly.

4.4.3.3 Benefits of Promulgating Future Work Practice Standards

A number of alternative control technologies are available to reduce radon-222 emissions and subsequent risks from tailings disposal. Both timing and disposal method affect the rate of emissions from tailings piles. The control alternatives, their emissions, and their potential benefits are reviewed here.

Emissions From New Model Impoundments

The single cell impoundment is the most prominent control technology used to dispose of radioactive tailings, and as such used as a yardstick with which to compare the performance of the alternative impoundments. The single cell impoundment or baseline, usually 47 ha (116 acres), has a 15-year active life and a surface area which is 80 percent wet or ponded during its active life. Final disposal, using earthen covers, is assumed to occur five years after closure. Radon-222 emissions from this impoundment in kCi per year are given in 5 year intervals for the first 20 years, in total for the last 75 years, and for the entire 100 year period in Table 4-44. Emissions from this impoundment are shown graphically by year in Figure 4-3. Radon-222 emissions remain fairly constant for the first fifteen years, at 0.8 kCi/y, increase during the drying phase to about 3.8 kCi/y, and decline to about .3 kCi/y once final cover, assumed to be 3-meters of earth, is applied.

Radon-222 emissions from both phased disposal and continuous single cell control technologies are also presented in Table 4-44. The phased disposal impoundment has six cells each with a surface area of 21.3 acres. Each cell holds one-sixth of the mill tailings generated during the 15-year operational period (roughly 2.5 years worth of tailings). Final cover, similar to the single cell impoundment, is applied after a five year drying period. Emissions from a single cell of the phased disposal impoundment during operation are zero because the cell is covered with water. After the first cell reaches capacity it is dewatered and begins a 5-year drying period during which time radon-222 emissions increase to a rate of approximately .7 kCi/y. Once the cell is dry a final earthen cover is applied. In other words, the final earthen cover is not started until 7.5 years after the cell began being filled. Meanwhile, a second cell is constructed, filled, and dewatered so that it too contributes to the level of emissions from the tailings. Emissions thus increase at 2.5 year intervals, as another cell reaches capacity and begins its drying out period. The emissions occurring after 3-meters of earth cover have been applied to dry cells are also shown in Table 4-44. The results show that when all six cells are covered emissions are constant at .31 kCi/y. Total emissions during the operating life of this impoundment are 8.94 kCi/y. While, the average emissions during this period are .60 kCi/y. This level of emission is lower than average emissions for the single cell of .834 kCi/y. Further, over a 100 year time period, the average emissions of .379 kCi/y is lower than the average emission rate of .48 kCi/y from the single cell impoundment. In the post-operational period, from 21-100 years, emissions of 24.42 kCi/y from phased disposal impoundments are higher than those from the single cell impoundments of 23.38 kCi/y. This difference is caused by differences in total surface area of the piles.

The other control technology considered is the continuous disposal of uranium mill tailings in a single large impoundment. Its surface area is analogous to the single cell impoundment. Emissions

Table 4-43. Estimated total cost for new tailings control technology.[a]
(in Millions of 1985 Dollars)

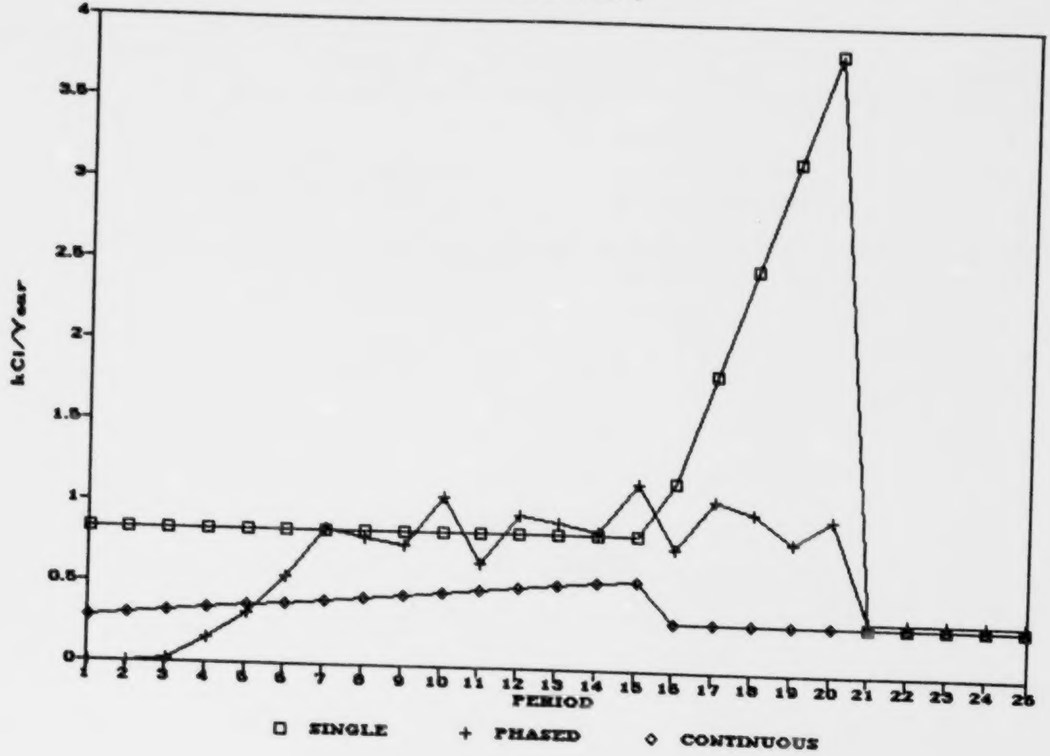
	Below Grade	Partially Below Grade
SINGLE CELL		
Total Cost	41.33	29.71
PHASED DISPOSAL		
One Cell	7.97	6.93
All (6) Cells	47.78	41.54
CONTINUOUS DISPOSAL		
Trench Design	54.16	47.75
Single Cell Design	N/A	37.44

Notes: (a) [PEI 86]; Based on comparable dimensions for cells.

Table 4-44. Radon-222 Emissions and Emissions Reductions Resulting from Alternative Work Practices (kCi).

	Single Cell Baseline	Phased Disposal			Continuous Single Cell		
Time Period	Emissions	Emissions	Emissions Reduction from Baseline	Emissions Reduction from Continuous	Emissions	Emissions Reduction from Baseline	Emissions Reduction from Phased
Operational Phase							
0-5	4.16	0.48	3.68	1.11	1.58	2.57	-1.11
6-10	4.16	3.96	0.20	-1.88	2.08	2.08	1.88
11-15	4.16	4.50	-0.34	-1.93	2.57	1.59	1.93
16-20	12.47	4.57	7.91	-3.09	1.48	10.99	3.09
Total	24.95	13.51	11.45	-5.79	7.71	17.23	5.79
Post Operational Phase							
21-100	23.38	24.42	-1.04	-2.52	21.9	1.48	2.52
All Phases							
0-100	48.33	37.93	10.41	-8.31	29.61	18.71	8.31
Annual Average	0.483	0.379	0.104	-0.083	0.296	0.187	0.083

Figure 4-3: Model Impoundment Emissions
(kCi/Year)



from this impoundment are estimated assuming that 1/15 of the surface area consists of dewatered tailings that are uncovered at any time over the 15-year operational life. The final 1/15 surface area is assumed to be covered at the end of the operational period. Emissions from this impoundment during operation are low, since the tailings which are dried by a vacuum filter prior to disposal can be covered immediately. Elimination of the drying period substantially reduces radon-222 emissions. The emissions from this impoundment are given in Table 4-44, and suggest that during the operational phase of the impoundment, on average, approximately .416 kCi/y of radon-222 contaminates the biosphere. These emissions are lower than either the baseline or the phased disposal technologies. Over the entire 100 year period, in comparison to the other control technologies, this impoundment on average discharges .296 kCi/y, the lowest level of radon-222.

Committed Fatal Cancers From New Model Impoundments

The risks associated with each type of impoundment are measured in terms of committed fatal cancers. Benefits of the phased and continuous impoundments are measured as the incremental reduction in committed fatal cancers. The risks are estimated from the following equation assuming that the model impoundment has an impact in proportion to that of the current licensed mills:

$$x = (y/z)(w) \tag{1}$$

where:

x = committed fatal cancers from model impoundments

y = total committed fatal cancers attributed to existing impoundments

z = emissions from existing impoundments

w = emission from model impoundment

Risks for a 100-year period, shown in Table 4-45, are estimated from equation (1) based on the rate of .0113 fatal cancers per kCi/y, and the emission rate from each impoundment. The continuous single cell approach always produces the lowest risk level. The phased disposal approach produces slightly higher risks than the single cell baseline during the post-operational phase, although it produces lower risks during the operational phase and over all phases.

The summary details of risk reductions that demonstrate this pattern are as follows: During the operational period the risk of cancer is reduced, relative to the single cell baseline, by 0.129 if

Table 4-45. Radon-222 Risks and Risk Reductions Resulting from Alternative Work Practices (committed cancers).

	Single Cell Baseline	Phased Disposal			Continuous Single Cell		
Time Period	Risk	Risk	Risk Reduction from Baseline	Risk Reduction from Continuous	Risk	Risk Reduction from Baseline	Risk Reduction from Phased
Operational Phase							
0-5	0.047	0.005	0.042	0.012	0.018	0.029	-0.012
6-10	0.047	0.045	0.002	-0.021	0.023	0.024	0.021
11-15	0.047	0.051	-0.004	-0.022	0.029	0.018	0.022
16-20	0.141	0.052	0.089	-0.035	0.017	0.124	0.035
Total	0.282	0.153	0.129	-0.066	0.087	0.195	0.066
Post Operational Phase							
21-100	0.264	0.276	-0.012	-0.028	0.247	0.017	0.028
All Phases							
0-100	0.546	0.429	0.117	-0.094	0.334	0.212	0.094
Annual Average	0.005	0.004	0.001	-0.001	0.003	0.002	0.001

phased disposal is adopted and by 0.195 if the continuous single cell method is used. The risk reduction associated with using the continuous single cell relative to the phased approach is 0.066. In the post-operational phase, phased disposal raises the risk by 0.012 while the continuous single cell approach lowers it by 0.017 relative to the baseline and by 0.028 relative to phased disposal.

4.4.3.4 Costs of Promulgating Future Work Practice Standards

Estimated Cost of New Model Tailings Impoundments

Costs for partially above-grade single cell, phased disposal, and continuous single cell disposal tailings impoundments are developed in Volume 2 of this *Environmental Impact Statement*.

Total costs for each design are shown in Tables 4-46 through 4-48, which indicate that the phased partially above grade disposal impoundment is the most expensive design ($ 54.02 million), while the single cell partially above grade impoundment ($36.55 million) is the least expensive. Costs for the continuous single cell design ($ 40.82 million) are only slightly more than those of the single cell impoundment, although the uncertainties surrounding the technology used in this design are the largest. The volumes or surface areas and the unit costs that were used in calculating the cost figures are also provided in Tables 4-46 through 4-48. The equations used to calculate volumes and surface areas are discussed in detail in the Volume 2 of this *Environmental Impact Statement* as are the sources and methods used to calculate unit costs.

This section reviews the costs associated with each of the control technologies discussed above. Present values of the costs for each impoundment are shown in Table 4-49. These costs are discounted over a 100-year period at the real rate of interest of 0, 1, 5, and 10 percent. The annualized costs discounted using the same real rates of interest are given in Table 4-50. The results suggest that the most costly technology is the phased disposal impoundment and the least costly is the single cell.

When these costs are annualized using the same real rate of interest, phased disposal technology is again found to be the most costly in comparison to not only the baseline but also to the continuous single cell impoundment when the real rate of interest is below 10 percent. When the real rate of interest is 10 percent, the continuous single cell approach becomes most expensive.

Table 4-46. Costs for a Single Cell Partially below Grade New Model Tailings Impoundment ($, 1988).

Item	Volume or Area (cu. mt. or sq. mt.)	Unit Cost ($/C.Y.)	Unit Cost ($/C.M.)	Cost ($,mil.)
Excavation	2,527,494	3.76	4.92	12.42
Grading	469,225	1.36	1.78	0.83
Cover				
Grade		1.36		
Compact		1.14		
Total	1,432,479	2.50	3.27	4.68
Gravel Cap	251,341	7.55	9.87	2.48
Riprap	138,408	23.00	30.07	4.16
Dam Const.				
Grade		1.36		
Compact		1.14		
Total	1,010,232	2.50	3.27	3.30
Synthetic Liner	442,405	11.16	13.35	5.91
Drainage Systems	641,089	0.50	0.60	0.38
Subtotal: Direct Cost				34.16
Indirect Cost @ 7 Percent				2.39
Total Cost				36.55

Table 4-47. Costs for a Phased Design Partially below Grade New Model Tailings Impoundment ($, 1988).

Item	Volume or Area (cu. mt. or sq. mt.)	Unit Cost ($/C.Y.)	Unit Cost ($/C.M.)	Cost ($,mil.)
Excavation	2,392,462	3.76	4.92	11.76
Grading	517,558	1.36	1.78	0.92
Cover				
Grade		1.36		
Compact		1.14		
Total	1,616,978	2.50	3.27	5.28
Gravel Cap	442,835	7.55	9.87	4.37
Riprap	181,013	23.00	30.07	5.44
Dam Const.				
Grade		1.36		
Compact		1.14		
Total	4,382,475	2.50	3.27	14.32
Synthetic Liner	451,901	11.16	13.35	6.03
Drainage Systems	1,066,682	0.50	0.60	0.64
Evaporation Pond				
Excavate		3.76		
Syn. Liner		11.16		
Total	88,387	14.92	19.50	1.72
Subtotal: Direct Cost				50.49
Indirect Cost @ 7 Percent				3.53
Total Cost				54.02

Table 4-48. Costs for a Continuous Design Partially below Grade New Model Tailings Impoundment ($, 1988).

Item	Volume or Area (cu. mt. or sq. mt.)	Unit Cost ($/C.Y.)	Unit Cost ($/C.M.)	Cost ($,mil.)
Excavation	2,527,494	3.76	4.92	12.42
Grading	469,225	1.36	1.78	0.83
Cover				
Grade		1.36		
Compact		1.14		
Total	1,432,479	2.50	3.27	4.68
Gravel Cap	251,341	7.55	9.87	2.48
Riprap	138,408	23.00	30.07	4.16
Dam Const.				
Grade		1.36		
Compact		1.14		
Total	1,010,232	2.50	3.27	3.30
Synthetic Liner	442,405	11.16	13.35	5.91
Evaporation Pond				
Excavate		3.76		
Syn. Liner		11.16		
Total	176,775	14.92	19.50	3.45
Vacuum Filter	N/A	N/A	N/A	0.92
Subtotal: Direct Cost				38.15
Indirect Cost @ 7 Percent				2.67
Total Cost				40.82

Table 4-49. Summary of Net Present Values of Alternative Work Practices
(1988 nominal dollars, millions)

		Work Practice					
		Phased Disposal			Continuous Single Cell		
Real Interest Rate	Single Cell Baseline	Phased Disposal	Incremental Cost from Baseline	Incremental Cost from Continuous Single Cell	Continuous Single Cell	Incremental Cost from Baseline	Incremental Cost from Phased Disposal
0 %	182.8	260.4	77.6	56.3	204.1	21.3	-56.3
1 %	167.7	234.4	66.8	41.9	192.5	24.8	-41.9
5 %	129.0	160.5	31.4	1.9	158.5	29.5	-1.9
10 %	105.3	108.4	3.1	-24.2	132.6	27.3	24.2

Table 4-50. **Summary of Annualized Costs of Alternative Work Practices (1988 nominal dollars, millions)**

		Work Practice					
		Phased Disposal			Continuous Single Cell		
Real Interest Rate	Single Cell Baseline	Phased Disposal	Incremental Cost from Baseline	Incremental Cost from Continuous Single Cell	Continuous Single Cell	Incremental Cost from Baseline	Incremental Cost from Phased Disposal
0 %	1.8	2.6	0.8	0.6	2.0	0.2	-0.6
1 %	2.7	3.7	1.1	0.7	3.1	0.4	-0.7
5 %	6.5	8.1	1.6	0.1	8.0	1.5	-0.1
10 %	10.5	10.8	0.3	-2.4	13.3	2.7	2.4

4.5 Economic Impacts

Any regulatory alternative will increase the cost of domestically produced U_3O_8. The amount of this impact will depend on the regulation selected. The impact of consumers and investors is evaluated assuming that the present value of the additional cost for future and existing piles was $250 million at a 10 percent real rate of interest. This figure is roughly equal to the incremental costs associated with a work practice for active plants that limits allowable emissions to an average of 20 pCi/m2/sec while in operation, a post-closure flux rate of no more than 2 pCi/m^2/sec, and assuming new impoundments utilize the phased disposal control presented in sections 4.4. In this section, the effects of such regulatory costs are evaluated. The impact of any of the alternative regulations from section 4.4 will be smaller and can be scaled from the impacts calculated here. If the U.S. uranium industry created an annuity payment to cover the added cost of this regulation, the payments required per year would be $66 million in each year for 5 years, or $41 million for each year for 10 years. The impact of these cost increases on investors in this industry or purchasers of electricity is also analyzed.

4.5.1 Increased Production Cost

The added production cost resulting from the regulation may, or may not, be passed on to the consumers of U_3O_8 (electric utilities). If the added cost is translated into higher prices for U_3O_8 *ceteris paribus*, then the consumers of electric power will ultimately be charged higher rates, depending on the rulings of state and local public utility commissions. Customers of utilities with a high reliance on nuclear generating capacity would face the highest increases. If the U.S. uranium milling industry is unable to pass on the disposal costs internalized by this regulation as a result of market competition from foreign producers or other factors, then the added cost will be ultimately paid by investors in the industry.

No attempt is made to quantify these impacts, instead a qualitative evaluation based on two extreme situations is made. The first case is based on the assumption that the uranium mills are unable to pass on the costs of regulation in the form of higher U_3O_8 prices. The second case assumes that the producers are able to recover all the costs associated with the disposal of tailings through increased U_3O_8 prices. The results generated under these assumptions then will provide the lower and upper bound, respectively, of the likely impacts. In fact, some of these costs will surely find their way into the rate base of utilities with nuclear generating capacity. In addition, since some owners of these existing impoundments are no longer operating nor do they have any intention of ever operating in this industry in the future, their cost of disposal must be borne by the investors in these firms.

It is assumed in the first case that no portion of the cost of the regulation can be passed on to the purchaser of U_3O_8. Selected average financial statistics for 1982-1986 from the domestic uranium industry (presented in Section 4.4) are given in Table 4-51. These data are compared to the present value cost impacts of the regulation and to the required annuity payment to amortize these costs over five or ten years. The 1982-1986 period is one in which the industry had been contracting and experiencing substantial losses due to excess capacity in production. The present value cost of the regulation would be about five times the industry losses over this period. It is equal to about 10 percent of the book value of industry assets and about 15 percent of industry liabilities.

In the second case it is assumed that the uranium industry is able to recover the entire increase in the tailings disposal cost be charging higher U_3O_8 prices. This increased input cost to electric utilities will ultimately be added to the rates paid by electric power consumers.

The revenue earned by the industry for generating 2.4 trillion kilowatt hours of electricity in 1986 was 121.40 billion dollars. The 1987 present value of the regulation (estimated to be $250 million) is less than 1 percent (.06%) of the U.S. total electric power revenue for the same year. Table 4-52 presents the relationship of the regulatory cost to power generation.

The increased cost of total generation reflects a change in the average cost per unit for the nation. The regional impacts will vary from this mean, based in part, on the dependence on nuclear power by region as shown in Table 4-53. The ERCOT region, for example, with no nuclear generating capacity would probably feel no effect from the cost of the regulation in higher electricity prices, and other regions, like MAIN and SERC would suffer the greatest effects. As for a specific customer or community, the level of impact is dependent upon the percent of generation from nuclear power that their particular electrical utility utilizes. For example, Commonwealth Edison of Illinois and Duke Power of North Carolina have two of the highest percentage of power from nuclear sources, so their customers would be more severely impacted than customers in other utilities.

Table 4-51. Comparison of the Present Value of the Estimated Cost of Impacts with Seclected Financial Statistics of the Domestic Uranium Industry: 1982-1986

Balance Sheet Accounts	Domestic Uranium Industry	Present Value Cost as a Each Industry Statistic	Annual Five Year Annuity Payment as a Percent of Each Industry Statistic	Annual Ten Year Annuity Payment as a Percent of Each Industry Statistic
Operating Revenue	712.5	35.1%	9.3%	5.8%
Net Income (LOSS)	(139.2)	-179.6%	-47.4%	-29.5%
Total Sources of Funds	265.1	94.3%	24.9%	15.5%
Capital Expenditures	55.5	450.5%	118.9%	73.9%
Total Uses of Funds	449.2	55.7%	14.7%	9.1%
Current Assets	478.6	52.2%	13.8%	8.6%
Total Assets	2,696.6	9.3%	2.4%	1.5%
Total Liablilities	1,689.4	14.8%	3.9%	2.4%

Note: Assume $250 million NPV cost, $66 million for 5 year annuity and $41 million for 10 year annuity.

4.5.2 Regulatory Flexibility Analysis

The Regulatory Flexibility Act (RFA) requires regulators to determine whether proposed regulations would have significant economic impact on a substantial number of small businesses or other small entities. If such an impact exits, they are required to consider specific alternative regulatory structures to minimize the small entity impacts without compromising the objective of the statute under which the rule is enacted. Alternatives specified for consideration by the RFA are tiering regulations, performance rather than design standards, and small firms exemptions. Most firms that own uranium mills are divisions or subsidiaries of major U.S. and international corporations. Many of these uranium milling operations are parts of larger diversified mining firms which are engaged in many raw materials industries and uranium represents only a small portion of their operations. Others are owned by major oil companies or by electric utilities who were engaged in horizontal and vertical integration, respectively, during the 1960s and 70s. In 1977, there were 26 companies operating uranium mills and at the start of 1986 only two were operating. The future of this industry suggests that only a limited number of these existing facilities will ever operate again. It is also expected that the high level of financial risk and capital requirements will continue to attract only large diversified firms and electric utilities to this industry. Thus, no significant impact on small businesses is expected.

Table 4-52. Impacts of Regulation on Electrical Power Industry.

	Total Electric Power Industry	Nuclear Electric Power Industry Only
1987 Million Killowatt-Hours Generation	2,572,127	414,038
Present Value of Added Costs for Disposal per Million Kilowatt-Hours	97.2	603.8
Annual Cost of 5 Year Annuity per Million Killowat-Hours	25.7	159.4
Annual Cost of 10 Year Annuity per Million Killowat-Hours	15.9	99.0

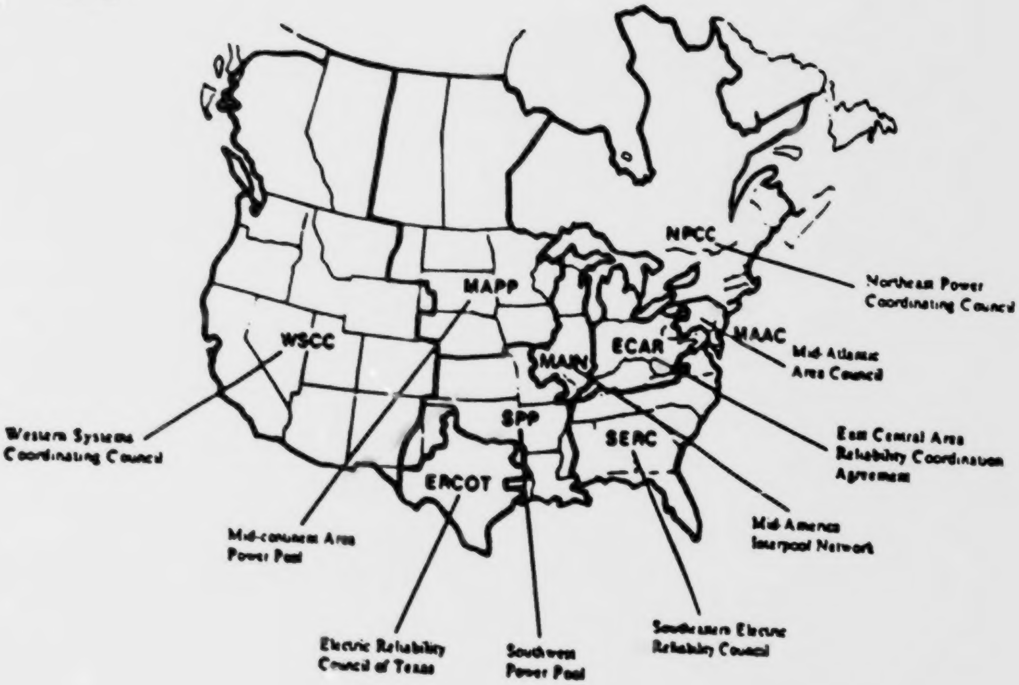
Note: Assume $250 NPV cost, $173 per Year for 5 Year Annuity, $97 for 10 Year Annuity.

Table 4-53. Electrical Generation by NERC Region, 1987

Region	Total Power Generated (GWH)	Nuclear Power Generated (GWH)	Nuclear Power as a Percent of Total Power
ECAR	441,993	28,766	6.5%
ERCOT	172,610	-	-
MAAC	191,621	60,885	31.8%
MAIN	185,405	67,659	36.5%
MAPP(U.S.)	125,383	22,795	18.2%
NPCC(U.S.)	205,808	52,182	25.4%
SERC	543,452	131,207	24.1%
SPP	237,132	37,881	16.0%
WSCC(U.S.)	457,404	53,895	11.8%

Source: DOE87a

KEY:


NPCC
Northeast Power Coordinating Council
MAPP
MAAC
Mid-Atlantic Area Council
WSCC
ECAR
MAIN
SPP
SERC
East Central Area Reliability Coordination Agreement
Western Systems Coordinating Council
ERCOT
Mid-America Interpool Network
Mid-continent Area Power Pool
Electric Reliability Council of Texas
Southwest Power Pool
Southeastern Electric Reliability Council

REFERENCES

AR86 The annual reports of all uranium-producing companies were examined for the years 1976-1986. The reference, AR, is followed by a date. The specific company reference is to be found in the text.

BC84 Bureau of the Census Population Projections

CO85 Industry and State of Colorado information

DOE85b Department of Energy, *Uranium Industry Annual 1984*, DOE/EIA-0478(84), October 1985.

DOE85c Department of Energy, *Commercial Nuclear Power: Prospects for the United States and the World*, DOE/EIA-0438(85), September 1985.

DOE87a Department of Energy, *Domestic Uranium Mining and Milling Industry: 1986 Viability Assessment*, DOE/EIA-0477(86), November 23, 1987.

DOE87b Department of Energy, *Uranium Industry Annual 1986*, DOE/EIA-0478(86), October 9, 1987.

DOE87c Department of Energy, *Commercial Nuclear Power 1987: Prospects for the United States and the World*, DOE/EIA-0438(87), July 31, 1987.

EPA82 U.S. Environmental Protection Agency, "Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192)," Vol. I, EPA 520/4-82-013-1, Office of Radiation Programs, Washington, D.C., October, 1982.

EPA83 U.S. Environmental Protection Agency, "Final Environmental Impact Statement for Standards for the Control of By-Product Materials from Uranium Ore Processing (40 CFR 192)," Vol. I, EPA 520/1-83-008-1, Office of Radiation Programs, Washington, D.C., 1983.

EPA86 U.S. Environmental Protection Agency, "Final Rule for Radon-222 Emissions from Licensed Uranium Mill Tailings," EPA 520/1-86-009, Office of Radiation Programs, Washington, D.C., August, 1986.

EPA89 *Risk Assessments*, Volume 2.

JFA85a Jack Faucett Associates, *Economic Profile of the Uranium Mining Industry*. Prepared for U.S. Environmental Protection Agency, January 1985.

JFA85b Jack Faucett Associates, communications with uranium mill operators and parent companies, June-October 1985.

MA83 Marline Uranium Corp. and Union Carbide Corp., "An Evaluation of Uranium Development in Pittsylvania County, Virginia," October 15, 1983.

MSHA Health and Safety Analysis Center, Mine Safety and Health Administration (MSHA), Department of Labor, "1987 Uranium Mines Address Listing with Workers and Employee Hours," Fourth Quarter, 9 February 1988.

NM85 Personal communication, Energy and Minerals Department, Mine Inspection Bureau, State of New Mexico, December 1985.

NRC80 U.S. Nuclear Regulatory Commission, "Final Generic Environmental Impact Statement on Uranium Milling," NUREG-0706, Washington, D.C., September, 1980.

Nugent80 Nugent, J.W., A Summary of Mineral Industry Activities in Colorado, 1980: Part II, Metal-Nonmetal," Colorado Department of Natural Resources, Division of Mines.

NUEXCO88 NUEXCO, *NUEXCO Monthly Report*, #233, February, 1988.

NUCO88j NUEXCO, *NUEXCO Monthly Report*, January, 1988.

OECD83 Organization for Economic Cooperation and Development, *Uranium: Resources, Production, and Demand*, Paris, December 1983.

PEI85a PEI Associates, oral communication, August-October 1985.

PNL84 Battelle Pacific Northwest Laboratories, *U.S. Uranium Mining Industry: Background Information on Economics and Emissions*, PNL-5035, March 1984.

Ro78 Robinsky, E.I., "Tailing Disposal by the Thickened Discharge Method for Improved Economy and Environmental Control," in Volume 2, *Proceedings of the Second International Tailings Symposium*, Denver, CO, May 1978.

Ro84 Rogers, V.C., K. K. Neilson and D. R. Kalkwarf, *Radon Attenuation Handbook for Uranium Mill Tailings Cover Design*, NUREG/CR-3533, prepared for the U. S. Nuclear Regulatory Commission, Washington, D.C., April, 1984.

TX85 Personal communication, Texas Railroad Commission, State of Texas, December 1985.

WY80 *Wyoming State Inspector of Mines*, 1980, 1981, and 1984 annual reports.

WA85 Personal communication, Department of Natural Resources, Division of Geology and Earth Resources, State of Washington, December 1985.

Zi79 Zimmerman, Charles F., *Uranium Resources on Federal Lands*, Lexington, MA: Lexington Books, 1979.

APPENDIX A
CALCULATION OF WATER COSTS

To maintain a constant moisture level on the tailing surfaces, sufficient water must be added to the piles to compensate for evaporation. This water can be pumped by the mill companies from groundwater sources or from rivers to which the mills have access and water rights. Hence, the cost of the water to the mills is the cost of the energy needed to pump it. These costs are based on the area to be saturated, evaporation rates, the vertical distance water must be lifted, and industrial electric rates. These data and the calculations of the costs are presented in tables 4A-1.

The amount of water required to compensate for evaporation depends on the area to be kept moist and on evaporation rates. Areas to be kept saturated range from 2.4 acres at White Mesa Mill to 146.8 acres at Ambrosia Lake Mill. Evaporation rates were obtained from the NOAA *Evaporation Atlas for the Contiguous 48 United States*.[7] The free water surface evaporation (FWS) map was used. According to the atlas, FWS "...closely represents the potential evaporation from adequately watered natural surfaces such as vegetation and soil."[8] Evaporation rates ranged from 33 inches per year at the Sherwood Mill in the State of Washington to 50 inches per year at the Ambrosia Lake Mill in New Mexico. Converting inches per year to feet per year and multiplying by the acreage to be kept saturated yields the number of acre-feet of water that must be replaced each year.

Since the mines and mills own rights to groundwater or river water, the cost of water is the cost of pumping it. Table 4A-1 converts the volume of annual water loss to evaporation measured in acre-feet per year to the weight of water pumped in pounds per year. The weight of water to be lifted ranges from 24 million pounds per year at White Mesa Mill to 1.6 billion pounds per year at Ambrosia Lake Mill. Table 4A-1 also shows the estimated vertical lift at each mill. Sherwood Mill has no need to pump water for the purpose of saturating tailings because it has surplus water from other operations. Homestake Mill must lift water 800 feet.

The work done pumping the water equals the product of the weight of water in pounds pumped times the vertical distance it is lifted. These computations are also performed in Table 4A-1. This product times two is the foot-pounds of work done in a normal year, assuming that the pumps used have 50 percent efficiency. This value is converted into kilowatt hours which is then multiplied by

---

[7] U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, NOAA Technical Report NWS 33, "Map 3 of 4: Annual FWS Evaporation", *Evaporation Atlas of the Contiguous 48 United States*, Washington D.C., June 1982.

[8] *Atlas*, p. 4.

Table 4A-1. Calculation of Cost of Water Required to Reduce Allowable Emissions to 20 pCi/m2/sec During Operations.

Mill/Site	Area to be Saturated	Annual Evaporation Rate	Annual Water Loss to Evaporation	Quantiy of Water Pumped			Estimated Vertical Lift	Total Work Done per Year 50% Efficient Pump		Unit Energy Cost	Total Energy Cost
	(acres)	(in/yr)	(acre ft/yr)	(cu-ft/yr)	(gallons/yr)	(pounds/yr)	(ft)	(ft-lb)	(kw-hr)	($/kw-hr)	($/yr)
New Mexico											
Ambrosia Lake	146.8	50	612	26,647,830	1,999,310,621	1,594,484,966	200	6.4E+11	240,300	$0.09	$21,627
Homestake	96	49	392	17,075,520	127,715,183	1,021,721,466	800	1.6E+12	615,923	$0.09	$55,433
Utah											
White Mesa	2.4	47	9	400,934	2,998,755	23,990,037	500	2.4E+10	9,039	$0.10	$904
Shootaring	3.5	40	12	508,200	3,801,047	30,408,377	500	3.0E+10	11,457	$0.10	$1,146
Washington											
Sherwood	32	33	88	3,833,280	28,670,755	229,336,043	0	0.0E+00	0	$0.10	$0
Wyoming											
Lucky Mc	127.9	43	458	19,959,228	149,283,682	1,194,269,457	500	1.2E+12	449,962	$0.10	$44,996
Shirley Basin	33.6	43	120	5,238,380	39,180,108	313,440,862	500	3.1E+11	118,094	$0.10	$11,809
Sweetwater	4.4	43	16	680,552	5,090,145	40,721,161	500	4.1E+10	15,342	$0.10	$1,534
Totals	446.6		1,707	74,343,924	2,356,050,296	4,448,372,369		3.9E+12	1,460,117		$137,449

Source: JFA Calculations

the cost of electricity per kilowatt hour to give the annual cost of water. Because Sherwood Mill does not have to pump water, its cost is zero. The highest pumping cost is for Homestake Mill in New Mexico. The annual cost of pumping one billion gallons of water per year 800 vertical feet is $55,000. The total cost for all mills is $137,000.

If the mills had to buy surface water rights the cost would be higher. For example, in New Mexico, surface water rights sold for $750 to $3000 per acre foot in 1988-89. At the lower price Ambrosia Lake Mill would have to pay $459,000 annually for water to compensate for evaporation. At the higher price, the cost would be $1.8 million annually. Water right prices do not account for the cost of transporting the water.

CHAPTER 5

HIGH-LEVEL WASTE DISPOSAL FACILITIES

5. HIGH-LEVEL WASTE DISPOSAL

5.1 Introduction and Summary

The facilities planned for the ultimate disposal of high-level nuclear waste have been designed to result in negligible releases of radionuclides to the environment. The benefits of further reductions of emissions are expected to be low and the costs per unit of benefit are expected to be high. No cost study has been conducted and no economic impact analysis can be performed.

5.2 Industry Profile

5.2.1 Introduction

This chapter addresses the ultimate disposal of high-level nuclear waste generated by the commercial nuclear power industry and by the Department of Defense. Although no facilities for this purpose currently exist, the federal government has taken responsibility for finding suitable permanent storage facilities. These facilities will be operated by the Department of Energy. The facility for the disposal of high-level waste from the nuclear power industry will be licensed by the Nuclear Regulatory Commission. Although the facilities will not be privately owned, it is expected that private contractors will be selected to operate them.

Two facilities devoted to the ultimate disposition of high-level nuclear waste are currently being planned. A third facility, a monitored retrievable storage facility (MRS) is also being planned. However, since the MRS facility is not to be used as a final disposal site, it is not considered in this report. The facilities under consideration are [EPA89]:

1) The Waste Isolation Pilot Plant (WIPP) -- under construction in Carlsbad, New Mexico.

2) The Yucca Mountain Geologic Repository -- not yet under construction, but to be located in Yucca Mountain, Nevada.

These facilities will be devoted to three types of waste [EPA89].

1) Spent nuclear fuel where there is no intent to reprocess;
2) High-level waste from the reprocessing of spent nuclear fuel; and
3) Transuranic wastes

The role played by each facility is discussed below.

5.2.2 Facilities for the Ultimate Disposal of High-Level Waste

The design features and operations of the two facilities under consideration are discussed below:

5.2.2.1 The Waste Isolation Pilot Plant (WIPP)

The WIPP is for the disposal of defense radioactive wastes, primarily transuranic wastes. The facility, currently being constructed in Carlsbad, New Mexico, performs the two main phases of waste disposal--first, the receipt and final packaging of the waste and, second, its permanent underground storage--at a single location. The packages it receives are of two types, contact-handled and remote-handled waste. Damaged casks are decontaminated, overpacked or repaired. They are then transported underground into a mined repository in a salt formation.

5.2.2.2 Yucca Mountain Geologic Repository

This facility, planned for construction in Yucca Mountain, Nevada, will first receive and package and then permanently store high-level wastes produced by commercial activities.

5.2.3 Demand for High-Level Waste Management

One of the major issues of the nuclear age is what to do with the high-level waste generated by nuclear power reactors and weapons production facilities. Spent fuel and other high-level wastes have accumulated on-site at nuclear power plants and weapons plants, and at interim storage sites.

The projected generation of spent fuel by the year 2000 [EPA89] will be 95,000 metric tons of heavy metal. The absence of a permanent storage site to handle spent fuel complicates the planning process for power companies and involves an interim storage cost for companies that operate reactors. High level waste management costs include both the cost of disposal and the cost of potential liability in the event of an accident. Thus, there is a very real demand for the services of high-level waste disposal facilities.

5.2.4 Supply of High-Level Waste Management

No facility for the management of high-level waste currently exists. However, two facilities are envisioned, one is in the planning stages, and one is under construction. The projected quantity of high-level and transuranic waste to be disposed of by the turn of the century is about 70,000 metric tons of uranium (MTU) or equivalent. Sixty-two thousand MTU of this will be spent fuel from civilian reactors and 8,000 MTU will be defense waste. The projected supply of high-level waste disposal falls short of the 95,000 MTU required to meet the needs of firms and agencies operating nuclear reactors [EPA89]. The difference will be made up by at-reactor storage and interim off-site storage. Thus, the projected services of the high-level waste facilities fall slightly short of the projected demand.

5.3 Current Emissions, Risk Levels, and Feasible Control Methods

5.3.1 Introduction

Since all facilities for high-level waste disposal are still in the planning or construction stages, there are no current emissions of radionuclides from the sites. However, estimates of the emissions have been made as part of the planning process. Most of the atmospheric emissions are expected to come from routine receiving, unpacking and decontamination of shipping casks, or from accidental droppage of casks during handling. All handling of the materials is to be done in "hot cells" which are equipped with multiple stage high-efficiency particulate air (HEPA) filters to remove most of the airborne contaminates before air from the hot cells is released to the atmosphere.

For most of the wastes, the casks in which they are shipped or stored are the major emission control devices. The HEPA filters are considered to be backup protection.

5.3.2 Current Emissions and Estimated Risk

Table 5-1 gives the total estimated quantities of radioactive emissions and the estimated risk for each facility under normal operation [EPA89].

Table 5-1: Emissions and Risks From Normal Operations at HLW Disposal Facilities.

Facility	Radionuclide	Release Rates (Ci/y)	Nearby Individuals Lifetime Fatal Cancer Risk	Regional (0-80 km) Population Deaths/year
Yucca	H-3	2.8E+2	7E-8	4E-6
	C-14	1.1E+1		
	Kr-85	1.4E+4		
	I-129	2.8E-2		
WIPP	Pu-238	6.6E-8	3E-10	2E-9
	Pu-239	4.6E-8		
	Pu-240	1.0E-8		
	Pu-241	2.8E-6		
	Am-241	1.6E-7		
	Cm-244	2.4E-8		

5.3.3 Control Technologies

Because the planned high-level waste management facilities are to be equipped with state-of-the-art control equipment, the cancer risk associated with release from these facilities is no greater than 1E-6. Accordingly, technologies for further reductions of these emissions were not evaluated nor were costs computed for reductions in emissions.

5.4 Analysis of Benefits and Costs

5.4.1 Introduction

The following sections discuss the costs and benefits of control technologies for high-level waste facilities.

5.4.2 Least-Cost Control Technologies

Radioactive emissions from the three high-level waste management facilities are entrained by the air flowing through a series of HEPA filters. Assuming that HEPA filters remove 99 percent of the particulates passing through them, 1 percent of the original emissions will be left. Assuming the costs of installing and operating an additional HEPA filter is the same as the cost of installing and operating the HEPA filter ahead of it, the cost per Ci/y removal by the last filter in line would be one hundred times as much, because the previous filter has removed 99 percent of the particulates entering it and leaves the next filter with just one percent as much input to filter.

5.4.3 Health and Other Benefits

The health benefits of adding another HEPA filter would be to reduce the incidence of cancer attributable to a facility to one percent of the original amount. Nationwide, the number of cancers attributable to these facilities would drop from 1E-6 per year to 1E-8 per year, a reduction of 9E-7.

5.5 Industry Cost and Economic Impact Analysis

Since this rulemaking does not involve a proposal for emission control for high-level waste management facilities beyond the levels in the proposed designs, it will have no economic impact. If there were proposals for further emission controls, they would affect an industry that has yet to be born and which would be in a position to pass on the associated costs to the federal government. The government could pass on some of the costs to the commercial nuclear power industry in fees collected in exchange for storage. The nuclear power industry is likely to benefit from the overall project, since one of the industry's major operational, planning and political problems is the handling and interim storage of high-level waste.

REFERENCES

EPA89 *Risk Assessment*, Vol. 2.

CHAPTER 6

DEPARTMENT OF ENERGY FACILITIES

6. DEPARTMENT OF ENERGY FACILITIES

6.1 Introduction and Summary

The Department of Energy (DOE) owns or directs the activities of numerous facilities across the country that emit radionuclides into the air. Twenty-seven facilities are mentioned in this chapter. The Feed Materials Production Center (FMPC) at Fernald, Ohio is discussed in chapter Seven.[1] The primary task of many of these facilities is the support of nuclear weapons production and research for the Department of Defense. Many of the facilities also support research of biomedical studies, environmental and safety aspects of nuclear energy, nuclear waste processing, advanced nuclear energy production, fusion research, non-nuclear energy studies, basic research in high energy physics, and training. The names and locations of these facilities are listed in Table 6-1.

Because each facility is unique, risk assessments were conducted on a facility by facility basis. The overall risk for all of these DOE facilities is estimated at 3E-1 fatal cancers per year.

6.2 Industry Profile

A wide variety of facilities and of functions that they fulfill are covered in this chapter. Broadly speaking the functions can be classified into nuclear weapons research and production, basic physics or energy research, nuclear waste disposal and management, reactor testing and training, medical applications or health effects of radionuclides, and environmental studies. Over a dozen facilities are involved partially or solely in nuclear weapons design, testing, and production. Over half a dozen are involved in the nuclear power production or research fields while at least four laboratories are conducting basic research in physics. Several facilities are involved in waste disposal and management activities and over half a dozen in health, biomedical, or environmental research.

The level of activities at these facilities is dependent upon a host of factors including past nuclear activities and their waste products; current and future military requirements, priorities, and funding levels; research for advanced nuclear power processes; waste disposal requirements and regulations; further research into health effects; and biomedical applications of radionuclides. Some of the facilities or their components are on stand-by status while others are closed down and decommissioned at this time.

---

[1] DOE recently arrived at an agreement with the State of Ohio to clean up this site.

Table 6-1: Department of Energy Facilities.

Facility	Location
Los Alamos National Laboratory	Los Alamos, New Mexico
Oak Ridge Reservation	Oak Ridge, Tennessee
Savannah River Plant	Aiken, South Carolina
RMI Company	Ashtabula, Ohio
Feed Materials Production Center	Fernald, Ohio
Hanford Reservation	Richland, Washington
Brookhaven National Laboratory	Long Island, New York
Mound Facility	Miamisburg, Ohio
Idaho National Engineering Laboratory	Upper Snake River, Idaho
Lawrence-Berkeley Laboratory	Berkeley, California
Paducah Gaseous Diffusion Plant	Paducah, Kentucky
Lawrence Livermore/Sandia Laboratory	Livermore, California
Portsmouth Gaseous Diffusion Plant	Piketon, Ohio
Argonne National Laboratory	Argonne, Illinois
Pinellas Plant	Pinellas County, Florida
Nevada Test Site	Nye County, Nevada
Knolls Atomic Power Laboratory	Kesselring, New York
Battelle Memorial Institute	Columbus, Ohio
Fermi National Accelerator Laboratory	Batavia, Illinois
Sandia National Laboratories/Lovelace	Albuquerque, New Mexico
Bettis Atomic Power Laboratory	West Miflin, Pennsylvania
Knolls Atomic Power Laboratory	Windsor, Connecticut
Rocky Flats Plant	Jefferson Co., Colorado
Pantex Plant	Amarillo, Texas
Knolls Atomic Power Laboratory	Schenectady, New York
Ames Laboratory	Ames, Iowa
Rockwell International	Santa Susana, California

6.3 Current Risk Levels and Feasible Control Methods

6.3.1 Introduction

The summary findings reported in this section are based upon an assessment of each facility which determined the emissions, source release point(s), demographic data, meteorological information, etc. The risk assessment utilizes the AIRDOS-EPA/DARTAB/RADRISK computer codes [EPA89]. Radionuclides that contributed at least 90 percent of the collective contribution are identified in the supporting documentation cited above. The specific processes and emission controls for some of the facilities such as the Oak Ridge Y-12 plant are classified.

Table 6-2 presents the risks to the populations living within 80 km of DOE facilities and the maximum estimated risk to nearby individuals for each facility.

6.3.2 Facility Descriptions

Emission characteristics by facility and radionuclide type and resultant risks are presented in the supporting documentation for each of the facilities [EPA89]. Discussion of the four facilities that result in effective dose equivalents of over 1 mrem/y follows. Although previously listed, RMI Company is no longer included in this discussion due to their installation of additional controls in 1988 which has reduced their EDE to below 1 mrem/y.

The Los Alamos National Laboratory has major sources emitting over a dozen radionuclides with no source contributing more than a small fraction of the emissions. Each of the facilities has its own control mechanisms which vary in removal or containment efficiency and effectiveness. Not all radionuclide emissions from Los Alamos National Laboratory are controlled.

Table 6-2 Summary of Estimated Risks Around DOE Facilities

Site	0-80 Km Population	Estimated Deaths per Year (0-80 Km)	Maximum Estimated Risk to Nearby Individuals (Lifetime)
Los Alamos Laboratory, NM	160,000	4E-03	2E-04
Oak Ridge National Lab, TN	160,000	3E-02	8E-05
Savannah River Plant, GA	550,000	2E-01	7E-05
RMI Co., OH	1,400,000	8E-04	4E-05
Feed Materials Production Ctr, GA	3,300,000	3E-03	3E-05
Hanford Reservation, WA	350,000	6E-03	3E-05
Brookhaven National Lab., NY	5,200,000	1E-03	2E-05
Mound Facility, OH	2,900,000	3E-03	1E-06
Idaho National Eng. Lab, ID	100,000	2E-05	6E-07
Lawrence Berkeley Lab., CA	5,000,000	3E-04	5E-07
Paducah Gaseous Diff. Plant, KY	500,000	1E-05	4E-07
Lawrence Livermore Lab./Sandia Livermore Lab., CA	5,300,000	1E-03	3E-07
Portsmouth Gaseous Diff. Plant, OH	620,000	9E-05	2E-07
Argonne National Lab., IL	7,900,000	8E-05	1E-07
Pinellas Plant, FL	1,900,000	2E-04	1E-07
Nevada Test Site, NV	3,500	3E-06	1E-07
Knolls Lab-Kesslring, NY	1,200,000	3E-05	1E-07
Battelle Memorial Inst., OH	1,900,000	3E-06	2E-08
Fermi National Lab, IL	7,700,000	1E-06	2E-08
Sandia National Lab./Lovelace, NM	500,000	8E-06	1E-08
Bettis Atomic Power Lab, PA	3,100,000	1E-06	1E-08
Knolls Lab-Windsor, CT	3,200,000	2E-06	8E-09
Rocky Flats Plant, CO	1,900,000	9E-06	1E-08
Pantex Plant, TX	260,000	7E-08	4E-09
Knolls Lab-Knolls, CT	1,200,000	10E-07	3E-09
Ames Laboratory, IA	680,000	9E-08	4E-10
Rocketdyne Rockwell, CA	8,800,000	7E-08	2E-11

Source: [EPA89]

Emissions from Oak Ridge Reservation are composed primarily of Xe-133, H-3 and Kr-85. The major release point is the central disposal facility source stack composed of three internal sources of radioactive exhaust, each with its own emission control technology. Practical control technologies require that the effluents be removed from low flow rate air streams which will require installation prior to the centralized stack.

The Savannah River Plant is used primarily to produce plutonium and tritium for use in the production of nuclear weapons. The largest sources of emissions are the fuel reprocessing areas, the three production reactors, and the heavy water rework plant. Tritium is released from six of Savannah's facilities while Argon-41 is released exclusively from the operating reactors in roughly equal proportions. Carbon-14 is released from the three operating reactors and the separation plants in roughly equal proportions. Tritium is the principal source of radiation dose to the off-site population.

Current controls at the Savannah River Plant utilize a continuous monitoring system to detect levels exceeding a specified limit. When emissions exceed the threshold limit the air flow is diverted to a Hopcalite stripper and zeolite beds for tritium removal. The efficiency level of the controls varies with operating conditions which cannot be reported for security reasons. Emission from the production reactors consists of a system of prefilters to remove particulates from the incoming air, moisture separators, HEPA filters, and charcoal filters for iodine removal.

Feed Materials Production Center produces uranium metal and other materials for DOE facilities. Raw materials are dissolved in nitric acid and separated by liquid organic extraction. The recovered uranium is reconverted to uranyl nitrate and processed further to become uranium tetraflouride. Purified metal is made by reacting the uranium tetraflouride with metallic magnesium in a refractory-lined vessel. These processes result in estimated lifetime fatal cancer risks to nearby individuals of 3E-5. Risks of fatal cancers to the population residing within 80 km is 3E-3 deaths per year. The number of persons living within 80 km of Feed Materials Production Center is 3.3 million.

The estimated risk levels for regional populations are shown in Table 6-2 for the baseline conditions. Only the Savannah River Plant and the Oak Ridge Reservation cause more than 1E-2 fatal cancer deaths per year. The maximum individual risk of 2E-4 was due to emission released from Los Alamos Laboratory in New Mexico. The risks for the other facilities are progressively less. Individual facility dosage levels are estimated and may be found in the supporting documentation [EPA89].

6.3.3 Control Technologies

The Los Alamos National Laboratory has a multiplicity of sources and emissions which are subject to further controls. The Meson Physics Facility which utilizes a linear proton accelerator could reduce its emissions by about 95 percent by using a holding tank approach at a cost of about $1.6 million in capital and $90,000 per year for operations.

The Oak Ridge Reservation has several components which are technically subject to supplementary controls including the Central Radioactive Gas Disposal Facility (CRGDF), various processes of the Y-12 plant, and the diffusion plant's purge cascade. Controls for tritium emitted in water vapors from CRGDF are feasible and can achieve 90 percent efficiency, at a capital cost of $1.66 million. Uranium-234 and -238 emissions can be further controlled by a second stage of HEPA filters which retain a 99 percent efficiency rate in series mode or can achieve a 99.95 percent efficiency in a primary control mode. The capital cost of adding HEPA filters to the fabrication facility is estimated to be $2.65 million. The increased power requirements and the cost of HEPA filter replacement will increase operating costs by about $92,000 per year. Significant additional costs may be incurred if there are additional structural requirements.

The Savannah River Plant could improve the collection efficiency of a number of elements of its operations. The 200-H area tritium facilities could reduce their normal emissions by 25 percent through the use of a palladium catalyst and the recycling of effluent gases through the stripper in combination with hydrogen swapping. The cost of these enhancements would be about $65 million with an expected system life of 15 years. A procedure that could reduce tritium emissions from production reactor area stacks by up to 90 percent after an extended period of steady state operations (about six years) is the use of vapor phase catalytic exchange with cryogenic distillation. Gross costs estimates for this process range from $20 to 40 million plus annual operating costs of $1.5 to 2 million with a 30 year system life. Emissions from the separation plants which are quite small could be subject to further controls. Carbon-14 can be captured by an absorber system based on flaked barium hydroxide octahydrate. The noble gases (particularly Kr-85) could be captured by one of several processes using cryogenic distillation, fluorocarbon absorption, or absorption on mordenite beds, all of which have a decontamination factors of about 100. Such off-gas treatment systems are estimated to cost $50 million per plant plus $3 million for operation annually.

The Feed Materials Production Center is discussed in chapter seven. Improvements to the current controls can be made by using Goretex bags instead of wool bags in its dust collection system coupled with continuous stack monitoring and administrative controls. HEPA filters could also be used as a supplementary control for particulates.

6.4 Analysis of Benefits and Costs

6.4.1 Introduction

Four alternatives for controlling radionuclide emissions were evaluated. The first two had no effect on either costs or benefits. The third alternative is to require controls on any facility from which the emissions exceed 3 mrem/y EDE (effective dose equivalent). Oak Ridge National Laboratory and Los Alamos National Laboratory would both have to install controls to meet alternative 3. Alternative 4 is to require controls on all facilities from which emissions exceed 1 mrem/y EDE. Savannah River and FMPC would have to install controls to meet alternative 4. So would Oak Ridge and Los Alamos, since alternative 4 is more stringent than alternative 3. Controls that would reduce emissions below 1 mrem/y at all four facilities are considered in the following.

Emissions estimates were made for all the facilities, both with and without the supplementary controls, where appropriate. Estimated dose equivalents and associated fatal cancer risks were also estimated. Some of these control technologies are not well demonstrated for these source types and may require further developmental efforts. Other supplementary controls are well established and not costly, but may provide only minor additional benefits. Some controls are not strictly speaking controls, but avoidance or minimization of initial contamination or activation and improved administrative or engineering procedures. Table 6-3 provides the risks to the 80 km population and to the most exposed individual both before and after installation of supplementary controls. Table 6-4 shows which controls are included in the analysis, the net present value (NPV) of their cost stream, and the decrease in risk to both the 80 km population and the most exposed individual.

6.4.2 Cost of Control Technologies

The control evaluated at Los Alamos National Laboratory was an atmospheric pressure storage system that delays the release of emissions until some products can break down. The estimated capital cost is $1,600,000 and the operating cost is $90,000. The NPV of these costs over a 25 year period, with a discount rate of 5 percent, is $2,792,000.

At Oak ridge the controls evaluated were combinations of HEPA filters and high-energy venturi scrubbers at three emission sources with capital costs of $800,000, $400,000 and $1,450,000 and

Table 6-3: DOE Facilities Fatal Cancer Risks With and Without Supplementary Alternative 4 Controls

	Annual Risk to 80 km Population			Maximum Individual Risk	
	Without Controls	With Controls		Without Controls	With Controls
Los Alamos Natl. Lab.	4E-3	2E-3		2E-4	2E-5
Oak Ridge Reservation	3E-2	7E-3		8E-5	2E-5
Savannah River Plant	2E-1	8E-2		7E-5	2E-5
FMPC	8E-4	9E-4		3E-5	1E-5
	----	----		----	----
TOTALS:	2E-1	9E-2	MAX:	2E-4	2E-5

Table 6-4: Controls, Risk Reduction, and Costs Associated With Meeting Alternative 4, by Facility

				Estimated Control Cost in Thousands		
Facility	Decrease in Regional Population Risk	Decrease in Maximum Individual Risk	Supplemental Control	Capital	Operating	NPV Discount Rate = 5% 25 Years
Los Alamos National Laboratory	2E-3	2E-4	Atmospheric Pressure Air Storage System	$1,600	$90	$2,792
Oak Ridge	2E-2	6E-5	HEPA Filter, Venturi Scrubber, Tritiated Water Sieve Dryer	$4,310	$92	$5,401
Savannah River	1E-1	5E-5	Vapor Phase Catalatic Exchange with Cryogenic Distillation, Integrated Off-Gas Treatment System	$130,000	$8,000	$236,561
FMPC	1E-4	2E-5	HEPA Filter	$4,200	$111	$5,564
	----			-----	-----	------
TOTAL:	9E-2			$140,110	$8,293	$250,319

operating costs of $29,000, $13,000, and $50,000 per year respectively. At a fourth emission source a tritiated water/ sieve dryer system would be installed with a capital cost of $1,600,000 and no operating cost. Capital costs for supplementary controls at Oak Ridge total $4,310,000 and operating costs total $92,000 annually. The NPV for supplementary controls at Oak Ridge is $5,401,000.

Supplementary controls evaluated at Savannah River include a vapor phase catalytic exchange with cryogenic distillation and an integrated off-gas treatment system. The first has an estimated capital cost of $20 to 40 million, taken here to be $30,000,000, and operating costs of approximately $2,000,000 per year. The second supplementary control has a capital cost of $50,000,000 per plant and an operating cost of $3,000,000 per year per plant. Two plants would be fitted with this control for a total capital cost of $100,000,000 and a total operating cost of $6,000,000 per year. The total for all supplementary controls required to meet alternative 4 at the Savannah River Plant is $130,000,000 for capital cost and $8,000,000 annually for operating costs. The NPV of the supplementary controls required by Savannah River to meet alternative 4 is $236,561,000.

To meet the requirements of alternative 4, FMPC will require installation of HEPA filters at a capital cost of $4,200,000 and an operating cost of $111,000 per year. The NPV of these costs is $5,564,000. These estimates do not consider structural modifications that might be needed in order to install the filters.

For all four plants the total capital cost of meeting the requirements of alternative 4 is estimated to be $140,110,000 and the yearly operating cost to be $8,293,000. The aggregated NPV of these costs evaluated with a five percent discount rate over a twenty-five year assumed life expectancy is $250,319,000. The NPV is somewhat insensitive to the choice of discount rates, varying from $347,435,000 when the rate is zero to $202,649,000 when the rate is ten percent.

6.4.3 Health and Other Benefits

The health benefits of supplementary controls are estimated through the application of computer models of emission dispersion and the resulting inhalation and ingestion of various radioactive constituents and their effect on the body. Table 6-3 presents summary information on both the 80 km population and the maximum individual risk of fatal cancer due to the four facilities analyzed here with and without supplementary controls required to meet alternative 4. In preparing these estimates, detailed organ exposures are calculated for each facility. The risk to nearby individuals and to regional populations of fatal cancer is also documented [EPA89]. The level of maximum individual risk ranges from a high of 2E-4 at Los Alamos to a low of 3E-5 at FMPC. With supplementary controls, the greatest maximum individual risk drops to 2E-5. The aggregated risk for 80 km populations drops to from 2E-1 to 9E-2 when alternative 4 is implemented.

6.5 Industry Cost and Economic Impacts

Since the costs of these control actions will be borne by the Federal government there is no assignable direct private industry cost. If controls were implemented at any of these facilities, the major burden would be in the form of higher taxes, increased government debt, or reduction in other government services.

REFERENCES

EPA89 *Risk Assessment*, Vol. 2.

CHAPTER 7

DEPARTMENT OF ENERGY RADON FACILITIES

7. DEPARTMENT OF ENERGY RADON SITES

7.1 Introduction and Summary

Five Federal facility sources of potential radon exposure are reviewed. Four of the five facilities are no longer active, but are repositories of previously discarded radioactive residues from uranium mining, mills, uranium metal production, assaying and storage of uranium materials. The fifth facility, the Feed Materials Production Center near Fernald, Ohio, continues to produce purified uranium metal and components for DOE facilities.

Estimates of radon emissions and flux rates are indicated as are the associated risks to the population from these emissions. The costs of further control of these emissions are estimated and the associated benefits are evaluated.

Seven fatal cancers every century are attributable to the operation of these facilities. Over half of these cancers can be traced to the Middlesex Sampling Plant.

7.2 Industry Profile

The Department of Energy (DOE) Radon source category consists of five sites owned or controlled by the Federal government and operated or maintained under the authority of DOE. These five sites are described in [EPA84]. They contain significant quantities of radium-bearing wastes and are:

- Feed Materials Production Center (FMPC),
- Niagara Falls Storage Site (NFSS),
- Weldon Spring Site (WSS),
- Middlesex Sampling Plant (MSP), and
- Monticello Uranium Mill Tailings Pile (MUMT).

7.2.1 Feed Materials Production Center (FMPC)

The FMPC is located near Fernald, Ohio, and is currently operated under contract by Westinghouse Materials Company of Ohio for the DOE. The facility produces purified uranium metal and components for use at other DOE facilities. The feed materials include ore concentrates, recycled uranium from spent reactor fuel, and various uranium compounds. Thorium can also be processed at the site. The primary source of radon emissions at the FMPC is pitchblende residues stored in two concrete storage tanks referred to as silos. The residues resulted from the recovery of uranium from pitchblende ores during World War II.

7.2.2 Niagara Falls Storage Site (NFSS)

The NFSS, located in Lewiston, New York, is a DOE surplus facility operated by Bechtel National, Inc. The 77 ha site is part of the former Lake Ontario Ordnance Works and is used solely for storage of uranium and pitchblende residues. The residues were formerly stored in six buildings that were originally part of the facility's water treatment plant and in a pile nearby. Subsequently, by the end of 1986, the residues were consolidated in the Interim Waste Containment Facility (IWCF).

Descriptions of the consolidation process can be found in the annual environmental reports [BEC87]. The IWCF structure comprises the short-term closure system for the wastes until the long-term management plan is completed. The selected long-term plan calls for in-place management as described in the final environmental impact statement [DOE86]. The IWCF occupies 4 ha of the site and measures 274 m by 137 m. The structure's outer perimeter is composed of a dike and cutoff wall, both of which are constructed of compacted clay which forms a finished structure with an engineered compacted clay cover that sits directly over the wastes and extends beyond the perimeter dike. This cover is the principal barrier against moisture intrusion and radon emanation. The 0.9 m of clay is covered with 0.3 m of general soil and 0.15 m of top soil.

7.2.3 Weldon Spring Site (WSS)

The WSS, located near Weldon Spring, Missouri, is a surplus DOE facility that also stores uranium and thorium wastes. The site was operated by Bechtel National, Inc. in a caretaker status until 1986 when M-K Ferguson Company assumed control as Project Management

Contractor for the WSS Remedial Action Project. The site consists of two separate properties: the 89 ha Weldon Spring Chemical Plant together with the Weldon Spring Raffinate Pits form one (WSCP), and the other is the 3.6 ha Weldon Spring Quarry (WSQ) area, which is about six kilometers southwest of the raffinate pits.

The raffinate pits area is a remnant of the Weldon Spring Chemical Plant. The pits received residues and waste streams from uranium mining operations and washed slag residues from uranium metal production. Pits one and two contain neutralized raffinates from these sources while pits three and four contain similar wastes plus thorium-contaminated raffinate solids from processing thorium recycle products. Surface water covers pits three and four continuously, but pits one and two may be occasionally exposed due to seasonal evaporation.

The quarry site was initially used to dispose of radioactive thorium in drums, and subsequently thorium-contaminated building rubble, process equipment, and contaminated equipment. The Army also subsequently disposed of TNT-contaminated stone and earth to cover these thorium residues and finally, in 1969, placed contaminated equipment and rubble from the chemical plant in the pits.

7.2.4 Middlesex Sampling Plant (MSP)

The MSP site of Middlesex, New Jersey, was used by the Manhattan Engineering District and the Atomic Energy Commission between 1943 and 1967 for sampling, weighing, assaying, and storing uranium and thorium ores. Upon termination of operations, the site was decontaminated and released to the U.S. Marine Corps for use as a training center. Radiological surveys of the site and nearby private residences revealed contamination from windblown materials and use of materials as fill. DOE took responsibility for the site and its cleanup, which was completed in 1982.

The Middlesex Municipal Landfill also required remedial action, which was initiated in 1984 and completed in 1986. The contaminated materials were consolidated in storage piles, which are surrounded by concrete curbing and covered with a hypalon material to prevent the movement of materials.

7.2.5 Monticello Uranium Mill Tailings (MUMT) Pile

The MUMT pile is located in Monticello, Utah, and has been inactive since 1960. Approximately 817,000 tons of uranium mill tailings were impounded in four separate areas. The Federal government purchased the mill in 1948. It was subsequently operated by the Atomic Energy Commission until 1960 when it was permanently shut down. The tailings were stabilized in 1961 by grading, leveling and diking. The tailings were then covered with 0.3 m of gravel and another 0.3 m of soil, which was seeded. Further demolition and decontamination activities were conducted in 1974 and 1975 to reduce radiation levels and improve the site's appearance but cover on the site remains poor. The 1986 environmental monitoring report concludes that the EPA standard for a flux rate of 20 pCi/m^2/sec is exceeded at all of the tailings piles [SE87].

7.3 Current Emissions, Risk Levels, and Feasible Control Methods

7.3.1 Introduction

Current emissions are a function of source types, concentrations of contaminants, and current control methods. Risk levels are a function of the emission levels, release points, demographic and meteorological factors, and the pathways for exposure or ingestion. Estimates of exposure and lifetime fatal cancer risks are given for people living near the facilities and those within an 80-kilometer radius. These risks are summarized in Tables 7-1 and 7-2. [EPA89] Supplementary control options and costs are also noted.

7.3.2 Current Emissions and Estimated Risk Levels

In the following sections the best available estimates of current emissions and risk levels are presented for each facility.

7.3.2.1 Feed Materials Production Center

The residues stored at FMPC are estimated to have a radium concentration of 0.2 ppm or about 200,000 pCi/g radium-226. The estimated 11,200 kg of residues contain about 1,760 Curies of radium. A report determined that the facility is within DOE and EPA guidelines and regulations for the emission of radon, but additional radon control was recommended to meet the dose standards in Subpart A of 40 CFR 191 should cracking in the silos occur

Table 7-1: Exposures and risks to nearby individuals from DOE Radon Sites.

Facility	Maximum Exposure (WL)	Maximum Lifetime Fatal Cancer Risk
FMPC	1.5E-6	2E-6
NFSS	1.8E-7	3E-7
WSS-WSCP	1.3E-4	2E-4
WSS-WSQ	5.6E-5	8E-5
MSP	1.0E-4	1E-4
MUMT	9.7E-4	1E-3

Source: [EPA89]

Table 7-2: Estimated Fatal Cancers Per Year In the Regional (0-80 km) Populations Around DOE Radon Sites.

Facility	Population	Fatal Cancers Per Year
FMPC	3,200,000	6E-4
NFSS	3,800,000	4E-5
WSS-WSCP	2,300,000	7E-3
WSS-WSQ*	2,300,000	3E-3
MSP	16,000,000	5E-2
MUMT	19,000	8E-3
Total	25,300,000	7E-2

* WSS-WSCP and WSS-WSQ affect the same 80 km population.

Source: [EPA89]

[Gr87]. Measurements were made of radon flux emissions from the silos in 1984 and 1985, but subsequent structural improvements have had a significant impact on the emission levels. Therefore, no current valid emission information is available.

Radon-222 release rates were estimated at 2.5 Ci/yr based upon the radium content of the residues and a calculated flux rate through the concrete domes and foamed exterior [Na 85]. The estimated radon flux rate is 85 pCi/m^2/sec. The cancer risk to the most exposed individual is about 2E-6.

7.3.2.2 Niagara Falls Storage Site

The NFSS consolidated the wastes on a 4 ha site at the IWCF. Radon measurements at the site boundary during 1986 range between 0.17 and 0.36 pCi/l, including background. The background level was monitored at 0.31 pCi/l. Measured flux rates for radon are not available from the pile. The current estimated releases as stated in the closure/post-closure plan are 0.25 Ci/yr. The estimated radon flux rate consistent with this annual estimate is 0.06 pCi/m^2/sec. The risk for the most exposed individual is about 3E-7.

7.3.2.3 Weldon Spring Site

The WSS's environmental radon monitoring program covers 31 sites. The boundary radon monitors at WSCP read between 0.18 and 0.49 pCi/l, including background. The readings from the background location were measured at 0.47 pCi/l, while off-site monitors north of the pits and closer than the background monitors recorded levels of 0.22 to 0.36 pCi/l. The on-site monitors at the raffinate pits and the quarry ranged between 0.31 and 0.64 and 0.24 and 1.86 pCi/l, respectively. The estimated release rates of Radon-222 are 29 Ci/y for the WSCP and 14 Ci/y for the WSQ. The estimated radon flux rates are 2.7 pCi/m^2/sec at WSCP and 3.7 pCi/m^2/sec at WSQ. The cancer risk to nearby individuals is estimated at 2E-4 for WSCP and 8E-5 for WSQ.

7.3.2.4 Middlesex Sampling Plant

Samples of the piles at the MSP show concentration of 40 pCi/g of radium-226. There are twenty monitors at the MSP, and one off-site background monitor. The monitoring reports indicate that the range of readings are 0.3 to 1.2 pCi/l, including background, at MSP, with the background site registering 2.0 pCi/l. The off-site location is apparently at a higher radiation level than the site itself. The radon flux rates are not available, but are estimated based on a source strength of 1 pCi/g of radium-226 resulting in 1 pCi/m^2/sec of radon-222. This results in an estimated radon flux rate of 40 pCi/m^2/sec. Given the dimensions of the waste piles, this converts to 25 Ci/yr not accounting for attenuation by the hypalon cover. The risk level for nearby individuals is 1E-4.

7.3.2.5 Monticello Uranium Mill Tailings Pile

The MUMT was found to exceed the EPA standard for radon flux of 20 pCi/m^2/sec at each of the four tailings piles. Radon emission measurements range from 133 to 765 pCi/m^2/sec for these piles and a portion of the pile has migrated by as much as 500 m off-site. The average flux rate of the material that has migrated is 40 pCi/m^2/sec or 37 Ci/yr. The estimated radon flux rate averaged over all the piles is 228 pCi/m^2/sec. The total radon-222 release is estimated by DOE at 1,595 Ci/yr [SE87]. This facility has the highest lifetime fatal cancer risk for nearby individuals of the five facilities considered in this chapter: 1E-3.

7.3.3 Control Technologies

Each of the five facilities was evaluated for supplementary controls and costs that would be required to reduce the radon emissions to levels of 20, 6, and 2 pCi/m^2/sec. This cost estimation assumed that all wastes remain at their current sites, that the current storage configurations would be maintained, and that the wastes would be covered with dirt to sufficient depth to reduce the radon emissions to the target levels.

The radon emission rate from the two FMPC silos, using the estimated 2.5 Ci/y source term is calculated to be 85 pCi/m^2/sec. The FMPC would require 2.1, 2.3, and 3.3 meters of dirt, costing $56,000, $79,000, and $83,000, respectively, to meet the target levels of 20, 6, and 2 pCi/m^2/sec.

The NFSS's current rate of radon flux of 0.25 Ci/yr is equivalent to 0.06 pCi/m^2/sec which is below the lowest target level; therefore, there are no additional costs to meet these goals.

Currently the pits and quarry at WSS contain water which keeps radon fluxes at the relatively low levels of 2.7 and 3.7 pCi/m^2/sec respectively. Therefore the flux rates meet the target levels of 2 and 6 pCi/m^2/sec without controls. However, before dirt can be applied to the pits, they must be dried out. When this is done, the flux rate increases to 460 pCi/m^2/sec at pits 1, 2, and 3 and to 11 pCi/m^2/sec at pit 4. The control flux rates were calculated assuming that the pits and quarry are dry. Earth cover of 1.6, 2.3, and 2.8 meters would be required to reduce the emission rates to 20, 6, and 2 pCi/m^2/sec, respectively for pits 1, 2, and 3. Pit 4 needs no cover to meet 20 pCi/m^2/sec, and .3 and .9 meters to meet 6 and 2 pCi/m2/sec, respectively. The associated costs are $1.73, $2.96, and $4.26 million. Control techniques have not been devised to achieve alternate radon levels for the quarry site.

The MSP site would require 0.8, 1.4, and 2.1 meters of dirt, with associated costs of $419,000, $720,000, and $997,000 respectively, to meet the target levels of 20, 6, and 2 pCi/m^2/sec.

Covering the MUMT piles exhibited the highest costs, requiring 2.4, 3.4, and 4.4 meters of earth to meet the target levels of 20, 6, and 2 pCi/m^2/sec at costs of $26.8, $39.2, and $50.2 million, respectively.

7.4 Analysis of Benefits and Costs

7.4.1 Costs and Benefits of Meeting Various Radon Flux Rates

The analysis considers only the incremental costs relative to the baseline of supplementary controls to meet the target emission levels of 20, 6, and 2 pCi/m^2/sec. The benefits are estimated as the number of fatal cancers avoided and the reduction in maximum individual risk by applying supplementary control measures to meet the three target emission flux rates. Proportional reductions in the emission rates are converted into proportional reductions in the risks. The benefits are estimated by calculating the nearby and regional (up to 80 kilometers distance) population exposure to the radionuclides. The population exposure levels and risks of fatal cancers are a function not only of the emissions and their controls, but also of the population distribution in the vicinity of the facility, the meteorology, farming and food distribution and consumption patterns, atmospheric transport of the contaminants, and the inhalation or ingestion pathways.

The controls for four of the five facilities are assumed to be completed within one year. Implementation of controls for the fifth facility, the Niagara Falls Storage Site (NFSS), is expected to take ten years, but explicit control costs were not provided since the current emission flux rates are already well below the lowest target levels and, as mention above, the interim remedial actions would temporarily increase the emission levels and the number of fatal cancers. The following paragraphs present the findings of the analysis for each of the facilities. Table 7-3 summarizes the benefits and costs of supplemental control measures needed to meet a flux rate of 20 pCi/m^2/sec. Table 7-4 provides the same measures for a flux rate of 6 pCi/m^2/sec and Table 7-5 for one of 2 pCi/m^2/sec.

7.4.1.1 Feed Materials Production Center

The FMPC facility is estimated to have an emission flux rate of 85 pCi/m^2/sec resulting in a fatal cancer risk rate of 6E-4 per year [EPA89]. The costs of further reducing the emissions to a target level of 20 pCi/m^2/sec is estimated at approximately $56,000, which would be expended in a single year to cover the wastes with a greater depth of dirt. On an annualized basis, given a discount rate of five percent, the cost would be $2,800 per year for one hundred years.

7.4.1.2 Niagara Falls Storage Site

The NFSS facility, as stated above, is the one facility that is already well below the target emission rates. The current emission strength of 0.25 Ci/yr translates into an equivalent radon flux of 0.06 pCi/m^2/sec which is three percent of the lowest target level of 2.0 and 0.3 percent of the highest target level of 20 pCi/m^2/sec. If the proposed remedial actions were taken, the emission levels would sharply increase for a period of ten years, thereby increasing the total numbers of cancers for the first 100 years by a factor of nearly ten, from 6.0E-3 to 4.6E-2. No costs of this remedial action were estimated since the facility already meets the target emission levels.

7.4.1.3 Weldon Spring Site

The WSS facility is composed of four pits at the WSCP site and a quarry, the WSQ, at another location with varying emission rates that also fluctuate due to seasonal weather patterns. The WSCP has an estimated radon flux of 2.7 pCi/m^2/sec and WSQ one of 3.7 pCi/m^2/sec. Together they generate a fatal cancer risk of 1E-2 per year or approximately 1 fatal cancer in a century. The WSCP pits are filled with water much of the time. When dry they would release radon at a flux rate of 460 pCi/m^2/sec at pits 1, 2, and 3 and 11 pCi/m^2/sec at pit 4. Dirt depths of up to three meters would be required to reduce the flux rates of the dried out

TABLE 7-3: Costs and reduced Risks Resulting from Covering the Sources to Lower Radon Flux Rates to 20 pCi/m^2/sec

Facility	Estimated Initial Radon Flux Rate (pCi/m^2/sec)	Control Costs	Annual Fatal Cancers in 80 km Population		Maximum Individual Risk	
			Resultant	Averted	Resultant	Reduction
FMPC	85	$56,000	1E-04	5E-04	5E-07	2E-06
NFSS	0.06	$0	4E-05	0E+00	3E-07	0E+00
WSS-WSCP*	199.6	$1,730,000	4E-02	-3E-02	1E-03	-9E-04
WSS-WSQ**	3.7	NA	3E-03	0E+00	8E-05	0E+00
MSP	40	$419,000	3E-02	2E-02	8E-05	2E-05
MUMT	228	$26,800,000	7E-04	7E-03	1E-04	9E-04
		TOTAL: $29,005,000	TOTAL: 7E-02	TOTAL: -4E-03	MAXIMUM: 1E-03	MAXIMUM: 9E-04

* Based on flux rates with pits dried out. Note that flux rate is currently 2.7 pCi/m^2/sec due to water cover. The risks therefore exceed the initial risks.

** No control has been devised for WSS-WSQ.

[Source: Calculations by JFA]

TABLE 7-4: Costs and Reduced Risks Resulting from Covering the Sources to Lower Radon Flux Rates to 6 pCi/m^2/sec

Facility	Estimated Initial Radon Flux Rate (pCi/m^2/sec)	Control Costs	Annual Fatal Cancers in 80 km Population		Maximum Individual Risk	
			Resultant	Averted	Resultant	Reduction
FMPC	85	$79,000	3E-05	6E-04	1E-07	2E-06
NFSS	0.06	$0	4E-05	0E+00	3E-07	0E+00
WSS-WSCP*	199.6	$2,960,000	2E-02	-9E-03	4E-04	-2E-04
WSS-WSQ*	3.7	NA	3E-03	0E+00	8E-05	0E+00
MSP	40	$720,000	9E-03	4E-02	2E-05	8E-05
MUMT	228	$39,200,000	2E-04	8E-03	3E-05	1E-03
		TOTAL: $42,959,000	TOTAL: 3E-02	TOTAL: 4E-02	MAXIMUM: 4E-04	MAXIMUM: 1E-03

* Based on flux rates with pits dried out. Note that flux rate is currently 2.7 pCi/m^2/sec due to water cover. The risks therefore exceed the initial risks.

** No control has been devised for WSS-WSQ.

[Source: Calculations by JFA]

[Source: Calculations by JFA]

TABLE 7-5: Costs and reduced Risks Resulting from Covering the Sources to Lower Radon Flux Rates to 2 pCi/m^2/sec

Facility	Estimated Initial Radon Flux Rate (pCi/m^2/sec)	Control Costs	Annual Fatal Cancers in 80 km Population		Maximum Individual Risk	
			Resultant	Averted	Resultant	Reduction
FMPC	85	$83,000	1E-05	6E-04	5E-08	2E-06
NFSS	0.06	$0	4E-05	0E+00	3E-07	0E+00
WSS-WSCP*	199.6	$4,260,000	5E-03	2E-03	1E-04	5E-05
WSS-WSQ**	3.7	NA	3E-03	0E+00	8E-05	0E+00
MSP	40	$997,000	3E-03	5E-02	8E-06	9E-05
HUMT	228	$50,200,000	7E-05	8E-03	1E-05	1E-03
		TOTAL: $55,540,000	TOTAL: 1E-02	TOTAL: 6E-02	MAXIMUM: 1E-04	MAXIMUM: 1E-03

* Based on flux rates with pits dried out. Note that flux rate is currently 2.7 pCi/m^2/sec due to water cover.

** No control has been devised for WSS-WSQ.

[Source: Calculations by JFA]

pits to as low as 2 pCi/m^2/sec for pits 1, 2, and 3. Pit 4 would require a cover of up to one meter to meet this lowest target level. There is insufficient information to develop a cost of achieving the supplementary control target levels for the quarry site [DOE88]. Once the pits are dried out and the higher fluxes are occurring, the total cost of supplementary controls sufficient to meet the target level emission rate of 20 pCi/m^2/sec at the pits is $1,730,000, while the annualized payment is $87,000. This would actually increase emissions and risk to the population and to the most exposed individual. Reducing the flux to 2 pCi/m^2/sec would reduce risks. This would cost $4,260,000.

7.4.1.4 Middlesex Sampling Plant

The MSP facility's emission rate is estimated at 40 pCi/m^2/sec, causing an estimated 5E-2 fatal cancers per year. Supplemental controls that meet the target emission rates would reduce the fatal cancer risks to between 3E-2 and 3E-3 per year. The supplemental control cost is between $419,000 and $997,000.

7.4.1.5 Monticello Uranium Mill Tailings Pile

The MUMT piles have an estimated emission rate of 228 pCi/m^2/sec, which could result in an estimated 8E-3 fatal cancers per year. The least stringent of the control levels (20 pCi/m^2/sec) would reduce the number of fatal cancers per year to 7E-4, while maintaining flux levels at 2 pCi/m^2/sec would further reduce the number of deaths by a factor of ten. The supplemental control costs would be $26,800,000.

7.4.2 Sensitivity Analysis

Tables 7-3, 7-4, and 7-5 presented data regarding the costs and benefits of meeting various flux rate standards at each facility. In the following, the effects of changing the flux rate standard and the social discount rate are demonstrated.

Tables 7-6 and 7-7 demonstrate that there is a small national benefit of reducing the target flux rate to 6 pCi/m^2/sec or to 2 pCi/m^2/sec. The first additional increment would provide four fewer fatal cancers nationally per century and the second two fewer.

Table 7-6: Reductions in Emissions and Cancer Rates Attributable to Controls: U.S. Total.

Flux Rate ($pCi/m^2/sec$)	Related Cancers (per year)	Averted Cancers (per year)
Baseline	7E-2	---
20	7E-2	-4E-3
6	3E-2	4E-2
2	1E-2	6E-2

[Source: Calculations by JFA]

Table 7-7: Incremental Costs and Risk Reductions for Various Flux Standards

Flux Standard (pCi/m^2/sec)	Total Control Cost	Incremental Control Cost	Fatal Cancers Averted (per 100 yr)	Incremental Reduction in Fatal Cancers (per 100 yr)
Baseline	$0	------	0E+00	------
20	$29,005,000	$29,005,000	-4E-01	-4E-01
6	$42,959,000	$13,954,000	4E+00	4E+00
2	$55,540,000	$12,581,000	6E+00	2E+00

[Source: Calculations by JFA]

The other factor in the costs and benefits analysis of section 7.4.1 was the question of discounting the costs to compute net present value. Table 7-8 demonstrates that for a 20 pCi/m^2/sec flux rate standard, calculation of NPV of the cost of national requirement of supplementary controls does not vary at all. This is because the costs are all at the beginning of the 100 year period of analysis, where changes in discount rates have no effect.

7.5 Industry Cost and Economic Impact Analysis

Since the costs of these control actions will be borne by the Federal government, there is no assignable direct private industry cost. Only the FMPC is currently operating; the other four facilities are now surplus or storage facilities solely and therefore do not raise on-going capital or operations and maintenance costs.

Table 7-8: Net Present Value of Cost of Supplemental Controls to Meet a Flux of 20 $pCi/m^2/sec$ at DOE Radon Facilities: U.S. TOTAL.

RATE	NPV (in millions of dollars)
0%	29.0
1%	29.0
5%	29.0
10%	29.0

Note: Values rounded to one decimal place.

[Source: Calculations by JFA]

REFERENCES

Bec86 Bechtel National, Inc., *Closure/Post-Closure Plan for the Interim Waste Containment Facility at the Niagara Falls Storage Site*, DOE/OR/20722-85, Oak Ridge, Tennessee, May 1986.

Bec87 Bechtel National, Inc., *Niagara Falls Storage Site. Annual Site Environmental Report*, Calendar year 1986, DOE/OR/20722-150, Oak Ridge, Tennessee, June 1987.

DOE86 U.S. Department of Energy, *Final Environmental Impact Statement. Long-term Management of the Existing Radioactive Wastes and Residues at the Niagara Falls Storage Site*, DOE/EIS-0109F, April 1986.

DOE87 U.S. Department of Energy, *Draft Environmental Impact Statement. Remedial Action at the Weldon Spring Site.* DOE/EIS-0117D, February 1987.

EPA84 U.S. Environmental Protection Agency, *Background Information Document for Final Rules, Volume II, Appendix C, Radon Emissions from Department of Energy and Nuclear Regulatory Commission-Licensed Facilities*, EPA 520/1-84-022-2, Washington, D. C., October 1984.

EPA89 *Risk Assessments*, Vol. 2.

Gr87 Grumski, Joseph T., *Feasibility Investigation for Control of Radon Emissions from the K-65 Silos*, Feed Materials Production Center, Westinghouse Materials Company of Ohio, July 30, 1987.

Se87 Sewell, Michael, and Larick Spencer, *Environmental Monitoring Report on Department of Energy Facilities at Grand Junction, Colorado, and Monticello, Utah*, for calendar year 1986, UNC/GJ-HMWP-2, UNC, Grand Junction, CO, March 1987.

Na85 Nazaroff, W. W., et al., *Atmospheric Environment*, 19:1:31-46, (1985).

CHAPTER 8

ELEMENTAL PHOSPHORUS

8. ELEMENTAL PHOSPHORUS PLANTS

8.1 Introduction and Summary

The Elemental Phosphorus Plant source category consists of five operating and three standby facilities that produce elemental phosphorus by the electric furnace method. These plants have been evaluated in previous EPA assessments under Section 112 of the Clean Air Act and are subject to the NESHAP (40 CFR 61, Subpart K) promulgated on February 5, 1985. The NESHAP established an emissions limit of 21 Curies per year (Ci/y) for polonium-210 (Po-210) released from calciners and nodulizing kilns.

This chapter updates the assessment made during the 1983-1985 radionuclides NESHAPS rulemaking period (EPA84). Revisions have been made where necessary to reflect the changes in emissions or control technology as reported to the EPA under provisions of the NESHAP. It also incorporates the exposure and risk assessments for two idle plants in Florida that were not addressed in the risk assessment of the 1984 rulemaking.

The five plants currently producing elemental phosphorus are owned by Monsanto Company, FMC Corporation, Rhône-Poulenc (Stauffer), S.A., and Occidental Petroleum Company. The current radionuclide emissions at each of these plants have been measured and current emissions control technologies have been evaluated. The feasibility of various emission control technologies was evaluated and the performance and cost of these alternatives evaluated.

Current emissions at each of the five operating plants are estimated as listed below:

Units: Ci/y

Facility	Po-210	Pb-210
FMC	10.	0.14
Monsanto	1.4	0.35
Stauffer, MT	0.74	0.11
Stauffer, TN	0.28	0.058
Occidental	0.31	0.064

These emissions are estimated to result in a national cancer incidence rate of 8E-02 per year (see section 8-3). Various alternatives for reducing both radionuclide emissions and risks are evaluated in the current study. A summary of these alternatives is presented in the table below. For each of nine different Po-210 emissions levels and for four combinations of control technologies, costs and benefits - measured in cancers per year - were determined. The first set of alternatives are based on emission levels ranging from 10 Ci/y of Po-210 to 0.01 Ci/y. In addition, four alternatives were evaluated that apply different combinations of control technologies to different plants. These are based on the size (measured in terms of annual elemental phosphorus production capacity) of the five plants under consideration.

Summary of Alternatives

Alternative	Incidence	Incremental Incidence Reduction	Total Incidence Reduction	Incremental Annualized Cost	Total Annualized Cost
EMISSIONS LEVELS					
I. (10.0 Ci/y)	8E-02	--	--	--	--
II. (2.0 Ci/y)	3E-02	5E-02	5E-02	2.43	2.43
III. (1.0 Ci/y)	2E-02	7E-03	6E-02	2.74	5.17
IV. (0.75 Ci/y)	2E-02	5E-03	6E-02	1.30	6.47
V. (0.60 Ci/y)	1E-02	5E-03	6E-02	1.52	7.99
VI. (0.20 Ci/y)	4E-03	8E-03	7E-02	4.34	12.33
VII. (0.10 Ci/y)	3E-03	9E-04	7E-02	15.59	27.92
VIII. (0.06 Ci/y)	1E-03	2E-03	8E-02	0.39	28.31
IX. (0.01 Ci/y)	3E-04	8E-04	8E-02	3.28	31.59
CONTROL TECHNOLOGIES					
I.	8E-02	--	--	--	--
X.	3E-02	5E-02	5E-02	2.43	2.43
XI.	2E-02	7E-03	5E-02	2.35	4.78
XII.	7E-03	1E-02	7E-02	12.70	17.48
XIII.	8E-04	6E-03	8E-02	12.02	29.50

I. No Additional Emissions Control Required
X. High Energy Scrubbers on Large Plants
XI. High Energy Scrubbers on All Plants
XII. Fabric Filters on Large Plants; High Energy Scrubbers on Others
XIII. HEPA Filters on Large Plants; 600 SCA Precipitators on Others

---

This chapter is divided into four sections. The following section, 8.2, is a profile of the elemental phosphorus (P_4) industry. It is followed by a description of current radionuclide emissions, risk levels and feasible control methods. Section 8.4 outlines both the reductions in risks and the increases in costs that could result from the installation and operation of these various control technologies on the different plants. The final section describes potential economic impacts.

8.2 Industry Profile

Production of elemental phosphorus (P_4) in the United States utilizes about 10 percent of all phosphate rock mined annually. Elemental phosphorus is used principally as an intermediate in the production of high purity phosphoric acids and salts as well as a variety of phosphorus chemicals for industry and home use. The major derivatives of elemental phosphorus are detergent phosphate materials, mainly sodium tripolyphosphate (STPP).

8.2.1 Demand

U.S. production of elemental phosphorus peaked in 1969 at 623 thousand short tons (tons), then declined steadily to a low of 359 thousand tons in 1985. In 1986, production of elemental phosphorus totalled about 364 thousand tons, a one percent increase over 1985, but a 42 percent decrease from 1969. Production in 1987, however, was only 343 tons [MCP85]. Plant production and shipments between 1964 and 1987 are listed in Table 8-1.

The manufacture of thermal or furnace grade phosphoric acid accounts for approximately 85 percent of domestic elemental phosphorus consumption. Other chemicals, principally phosphorus pentasulfide, phosphorus pentoxide, and phosphorus trichloride use over 10 percent. Direct uses, miscellaneous chemicals and alloys consume less than 5 percent [MCP85]. A chart of the intermediate and end products of the elemental phosphorus industry is provided in Table 8-2 below.

Phosphorus is used principally as an intermediate in the production of high purity phosphoric acids and salts, as well as a variety of phosphorus chemicals for industry and home use. Detergent phosphate materials, chiefly sodium tripolyphosphate (STPP), are the major commercial derivatives of elemental phosphorus. Commercial phosphates also include other sodium phosphates, and calcium and potassium phosphates, used in a variety of detergents, cleaners, personal care products, water treatment and food. The detergent market is comprised of household detergents (85 to 90 percent) and industrial detergents (10 to 15 percent). Accounting for over 60 percent of elemental phosphorus use in 1970, detergent applications have since declined because of environmental concern regarding the role of phosphorus in eutrophication.

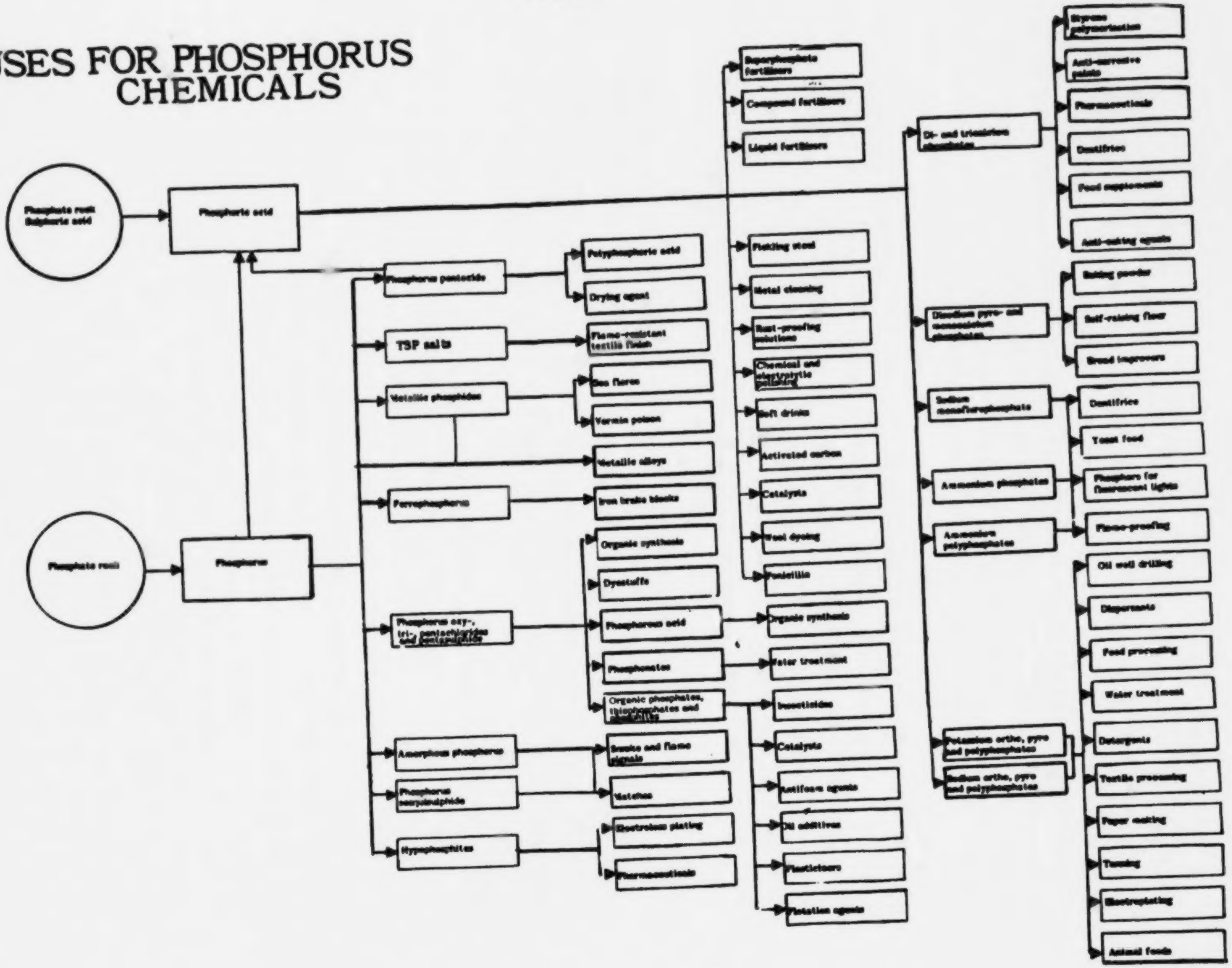
Table 8-1: Production and Shipment of Elemental Phosphorus -- 1964-1987 (Tons).

Year	Production	Total Shipments Including Interplant Transfers
1987	343,329	--
1986	363,717	324,665
1985	359,196	319,700
1984	386,063	342,155
1983	365,622	326,319
1982	361,189	360,472
1981	426,067	376,262
1980	431,730	429,462
1979	459,541	462,259
1978	441,274	442,619
1977	430,291	423,620
1976	436,655	425,374
1975	449,506	424,305
1974	524,175	497,612
1973	525,523	488,527
1972	540,089	502,197
1971	545,089	502,197
1970	596,555	549,920
1969	622,982	567,997
1968	613,343	567,531
1967	587,006	536,166
1966	565,550	512,583
1965	555,368	512,459
1964	503,880	452,324

Source: Bureau of the Census, U.S. Department of Commerce, *Current Industrial Reports: Inorganic Chemicals*, annuals, 1968,-1987, Table 1.

Table 8-2

USES FOR PHOSPHORUS CHEMICALS



Controls or bans on the use of phosphates in detergents have been in place for some time in New York, Indiana, Michigan, Wisconsin, Minnesota, Connecticut, and Maine. In the past two years, the District of Columbia, Virginia, Maryland, and North Carolina have restricted phosphate use. South Carolina, Oregon and Illinois are considering phosphate bans. Phosphate-containing detergents are now unavailable to about 30 percent of the U.S. population and to 100 percent of Canada's [CW88J]. The use of STPP in detergents has dropped from 1.4 billion pounds in 1980 to 1.2 billion pounds in 1985, and is predicted to fall to 1.1 billion pounds by 1990 [CW88j].

Metals treating is a second major end use of elemental phosphorus. Valuable in controlling corrosion, phosphorus is used in aluminum polishing and paint bases. Demand for phosphorus in metals treating depends heavily on demand for automobiles and durable goods, the major end users of these products, and thus tends to fluctuate with the business cycle. For example, with a slump in the automobile and other consuming industries between 1979 and 1980, consumption of elemental phosphorus products by these industries fell by 25 to 33 percent [CEN84, CEN81].

A third major market for elemental phosphorus is the food and beverage industry. Phosphoric acid is used in soft drinks, powdered drinks, baby foods, puddings, baking powder, and dentrifices, for example. Demand for these products has grown slowly in the past decade, but has been below the industry's forecasts, possibly because of the decline in sales of cakes and cookies as part of the national trend toward physical fitness, and a reformulation of soft drinks [CEN83, CEN81].

Chemical derivatives of phosphorus, other than phosphoric acid, at 10 percent of consumption, are equal to the food and beverage industry in importance to the elemental phosphorus market. Current uses include lubricating oils, insecticides, flame-resistant textile finishes, matches, and pharmaceuticals. In the last half of the 1970s, these uses were considered the market with the highest growth potential. Some companies added capacity during the period to produce pentasulfide, trichloride, and oxychloride phosphorus compounds, which are then used in agricultural chemicals, lubricating oil additives, and many other products. However, growth in these uses has been impeded by the longer life of lubricating oils, and competition from substitute products. Furthermore, though in the early 1980s producers increased investment in R&D, no new significant uses of phosphorus products have been discovered. Growth in non-acid uses has been about 3 percent per year since the middle 1970s [CEN81, CEN78].

The export market is the only other major consumer of U.S.-produced elemental phosphorus. Most countries that have a continuing requirement for phosphorus produce it domestically, largely because water transportation requires extensive precautions. However, exports have accounted for some 5 to 7 percent of U.S. elemental phosphorus production since the middle of the 1970s [CEN84, CEN79]. In 1986, most of the 22 thousand short tons (6.1 percent of production) of elemental phosphorus exports were destined for Japan (42 percent), Brazil (32 percent), Mexico (14 percent), and Taiwan (7 percent) [MY87].

Annual U.S. consumption of elemental phosphorus appears to have dropped to a plateau in the range of 325 to 350 thousand tons per year. Some industry observers expect long term domestic demand to increase at up to 2 percent per year. More pessimistically, U.S. demand will remain essentially unchanged or decline slightly. Consumption would decline if the ban on phosphate detergents were accentuated or if organophosphate pesticides were to lose additional market share. Most other applications, such as use in metal finishing and flame retardants, will probably have relatively static demand patterns, subject to swings in the overall economy [CEN84].

8.2.2 **Supply**

In 1988, four corporations operated a total of five elemental phosphorus plants in the United States. The largest producer is FMC Corporation (1 plant), followed by Rhône-Poulenc, which purchased 2 Stauffer Chemical plants in 1987, Monsanto (1 plant) and Occidental (1 plant). The corporations, plants, capacity, and plant employment are listed in Table 8-3.

Elemental phosphorus producers are vertically integrated which means that most of the P_4 produced is used captively downstream in other company operations. All producers operate phosphate rock mines in the vicinity of their elemental phosphorus plants. After manufacturing the elemental phosphorus, producers ship it to burning plants, where it is converted to other chemicals for use in consumer and industrial products. For example, elemental phosphorus produced at FMC's Pocatello plant is shipped to five other plants for production of phosphorus-based chemicals [FMC86]. The mix of chemicals produced varies, depending on the producer's cost and market structure. Table 8-4 presents the location of and phosphorus chemical production capacity at the various downstream plants of each company.

Table 8-3: Elemental Phosphorus Producers and Estimated Capacity.

Producer	Plant Location	Capacity (1987 tons/year)	Employment (1987, est.)
FMC	Pocatello, ID	137,000	650
Monsanto	Soda Springs, ID	95,000	400
Rhône-Poulenc[a]	Mt. Pleasant, TN	45,000	305
	Silver Bow, MT	42,000	190
Occidental	Columbia, TN	57,000	275
TOTAL		376,000	1,820

[a] In September, 1987, Rhône-Poulenc, a French company, acquired the inorganic chemicals businesses which had belonged to the Stauffer Chemical Company.

Source: Industry Information

Table 8-4: U.S. Capacities for Phosphorus and Phosphorus Chemicals - 1985.
(thousands of short tons)

Company and Plant Location	Phosphorus (P4 Basis)	Thermal Phosphoric Acid (P4 Basis)	Basic Inorganic Intermediates PCL3 (elemental	 P2S5 phosphorus	 P2O5 (P4) Basis)	Sodium Hypophosphate (P4 Basis)
ALBRIGHT & WILSON, INC.[a]						
Charleston, SC	--	8	6	--	--	--
Fernald, OH	--	15	--	--	--	--
FMC						
Carteret, NJ	--	26	--	--	--	--
Green River, WY	--	33	--	--	--	--
Lawrence, KS	--	61	--	6	--	--
Newark, CA	--	52	--	--	--	--
Nitro, WV	--	--	5	--	--	--
Pocatello, ID	137	--	--	--	--	--
MONSANTO						
Anniston, AL	--	--	--	7	--	--
Augusta, GA	--	36	--	--	--	--
Carondelet, MO	--	36	--	--	--	--
Columbia, TN	78	--	--	--	--	--
Kearny, NJ	--	36	--	--	--	--
Long Beach, CA	--	29	--	--	--	--
Milwaukee, WI	--	3	--	--	--	--
Sauget, IL	--	--	12	8	--	--
Soda Springs, ID	95	--	--	--	--	--
Trenton, MI	--	47	--	--	--	--
OCCIDENTAL						
Columbia, MS	--	--	--	--	--	--
Godwin, TN	57	11	--	--	--	--
Jefferson, IN	--	21	--	--	--	--
Miller, TX	--	21	--	--	--	--
Niagara Falls, NY	--	--	3	--	1.1	1.8
CHESEBROUGH-POND'S (STAUFFER)						
Chicago, IL	--	15	--	--	--	--
Chicago Heights, IL	--	26	--	--	--	--
Cold Creek, AL	--	--	3	--	--	--
Gallipolis Ferry, WV	--	--	5	--	--	--
Morrisville, PA	--	26	3	6	--	--
Mt. Pleasant, TN	45	--	--	6	3	1.6
Nashville, TN	--	18	--	--	--	--
Richmond, CA	--	9	--	--	--	--
Silver Bow, MT	42	--	--	--	--	--
Tarpon Springs, FL	--	--	--	--	--	--
TOTAL	454	529	38	32	4.1	3.4

[a] Albright & Wilson, Inc.'s thermal acid and phosphorus chemicals plants were purchased by Albright & Wilson, Ltd. (subsidiary of Tenneco, Inc.) from Mobil Corporation early in 1985.

Source: [SRI86]

With recent flat demand and little future growth expected, capacity for elemental phosphorus has been reduced. It is unlikely that facilities previously closed in Florida in the early 1980s will be restarted, since electric power costs, which account for about 20 percent of total production costs, are significantly higher there than in Tennessee and in the Northwest. Capacity in Tennessee was also reduced as demand weakened. Most recently, in 1986, Monsanto shut down its plant in Columbia, TN.

With the various shutdowns and consolidations, the real U.S. capacity for elemental phosphorus has dropped, from its peak of 686,000 tons in 1969, to about 360,000 tons at the end of 1987 [MCP85]. Capacity in the industry from 1964 to 1987, by producer, is presented in Table 8-5.

All elemental phosphorus producers in the U.S. are major corporations, with the smallest corporation, Stauffer, ranked in 1985 as number 235 in *Fortune*'s list of the 500 largest U.S. Companies. Since the acquisition of Stauffer's inorganic chemical operations by Rhône-Poulenc in 1987, FMC, ranked in 1987 as number 131 in Fortune's list, is the smallest corporation producing P_4 in the U.S. Elemental phosphorus represents a relatively small portion of the total revenues from corporate production, ranging from an estimated 0.5 percent for Occidental to 5.6 percent for FMC (Table 8-6). Since elemental phosphorus is an intermediate good consumed in other company products, however, its importance to company operations is more significant than revenues would indicate.

The operating and market characteristics of each producer are described below.

8.2.2.1 Monsanto Company

In 1985, Monsanto, with a total of 168,000 tons per year of operating capacity in two elemental phosphorus plants, was the largest producer of elemental phosphorus. The Soda Springs, Idaho plant, with three furnaces, was built in the middle and late 1960s and rated at 90,000 tons per year of capacity. The Columbia, Tennessee plant, with six furnaces, was constructed in the 1940s and modernized in the 1960s [SRI86]. Originally rated at 134,000 tons per year, operating capacity was reduced to 78,000 tons [CEN84]. This plant was shut down in 1986, leaving Monsanto with only 95,000 tons per year operating capacity.

Monsanto is the most diversified producer of elemental phosphorus, dominating in most of the nonagricultural markets. The company has been aggressive in developing new markets and upgrading

Table 8-5: Elemental Phosphorus Production Capacity.

PRODUCER CAPACITY (Thousands of Tons per Year)

	1964	1966	1969	1972	1975	1978	1981	1985	1987	1989[a]
AAC, Pierce, FL[b]	40	30	22	11	11	20	20	-[c]	-	-
FMC, Pocatello, ID	75	100	145	145	145	145	145	137	137	137
Occidental, Columbia, TN	69	69	70	45	57	57	57	57	57	57
Occidental, Niagra Falls, NY	6	-	-	-	-	-	-	-	-	-
Monsanto, Columbia, TN	110	110	135	135	135	120	134	78	-	-
Monsanto, Soda Springs, ID	40	80	110	110	110	110	95	95	95	95
Rhône-Poulenc, Mt. Pleasant, TN	80	80	63	55	45	45	45	45	45	45
Rhône-Poulenc, Silver Bow, MT	30	30	42	42	42	37	37	42	42	42
Rhône-Poulenc, Tarpon Springs, FL	13	13	23	25	25	23	23	-	-	-
TVA, Wilson Dam, AL	36	36	40	18	36	-	-	-	-	-
Mobil, Charleston, SC	8	10	8	-	-	-	-	-	-	-
Mobil, Nichos, FL	6	6	4	5	5	8	-	-	-	-
Mobil, Mt. Pleasant TN	-	20	24	-	-	-	-	-	-	-
TOTAL	513	584	686	591	610	565	556	454	376	376

[a] SRI estimate

[b] Producer became Continental Oil (1966), Agrico (1972), Holmes (1975), Electro-Phos (1978), and Mobil (1981).

[c] - represents no production.

Sources: [SRI86], [CMR81] and Industry Information

Table 8-6: Revenues from Elemental Phosphorus Production and Total Corporate Revenues (1986).

	Estimated Elemental Phosphorus Revenue[a] (in millions)	Total Corporate Revenue (in millions)	Elemental Phosphorus as a Percent of Total Revenue
FMC	$174.7	$3,078.9	5.7%
Monsanto	$121.1	$6,879.0	1.8%
Rhône-Poulenc	$110.9	$8,107.8	1.4%
Occidental	$72.7	$15,525.2	0.5%
TOTAL	$479.4	$33,590.9	1.4%

[a] Estimated revenue = estimated production x price
Estimated production = 85 percent of capacity
Price = $0.75 per pound or $1,500 per ton
Revenue for Rhône-Poulenc = 51,642 FF x $0.157/FF

P_4 to high-value specialty products. The company's share of each end use market within the industry, and the share of each end use within the company's line of phosphorus products, are listed in Tables 8-7 and 8-8 [SR180].

The value of production from Monsanto's elemental phosphorus plants in 1983 is estimated to have amounted to $199.5 million (Table 8-6), or 1.7 percent of total corporate revenues of $6,879.0 million.

8.2.2.2 FMC Corporation

The second largest American producer of elemental phosphorus is FMC Corporation. FMC operates a single plant, with four furnaces and an operating capacity of 137,000 tons per year, in Pocatello, Idaho. Furnaces in the plant are maintained on a rotating schedule in which each furnace is completely refitted or rebuilt every six to eight years [SR183].

Phosphate rock for FMC's elemental phosphorus plant is obtained from low grade shale at the Gay mine, a mine operated jointly by FMC and Simplot. The entire FMC share (80 percent) of the Gay mine's output is used to produce elemental phosphorus. With the Gay mine expected to be depleted by 1990, FMC will probably shift its mining to land it has leased or subleased from Federal and State governments in Caribou County, Idaho. The company is believed to hold all the permits required for this change [SR186]. Simplot operates the mine and supplies FMC with 1.5-1.6 million tons of 53-54 percent BPL furnace grade rock per year.

FMC's largest market area for its elemental phosphorus products is in builders and water treatment for detergents, with other market areas small by comparison. Details of FMC's market position are provided in Tables 8-9 and 8-10 [SR183].

In 1986, the value of elemental phosphorus production for FMC was approximately $174.7 million, or 5.7 percent of total corporate revenues of $3,078.9 million (Table 8-6).

8.2.2.3 Rhône-Poulenc (Stauffer)

The subject of numerous acquisitions in recent years, the Stauffer Chemical Company has changed completely since 1985. Effective March 15, 1985, Chesebrough-Pond's, Inc., a $3 billion per year producer of toiletries and food products, acquired Stauffer for approximately $1.3 billion. At the

Table 8-7: Elemental Phosphorus Market Share: Monsanto.

Products	Share of Monsanto's (1982) (%)	Share of Industry Market[a] (1982) (%)
Acid Uses		
Builders and Water Treatment	50	35
Foods, Beverages, and Toothpaste	14	34
Metals Treating	2	9
Exports, Other	19	35
Non-Acid Uses	15	35
TOTAL	100	29

[a] In 1982, part of the market for elemental phosphorus was held by wet-process acid producers and by Mobil, a furnace acid producer who is not currently in the market. Thus, market shares for the producers discussed here do not sum to 100 percent.

Table 8-8 Monsanto's Position in Phosphorus Markets -- 1984.

	Percent of Total Company P_4	Percent of Total U.S. Market P_4 Basis
Thermal Acid and Derivative Products	72	32-35
Non-Acid Uses		
PCL_3	4	30
P_2S_5	5	34
P_2O_5	-	-
Sodium Hypophosphate	-	-
Export, Other	19	74
TOTAL	100	38[a]

[a] Estimated company share of total U.S. elemental phosphorus market.

Source: [SRI86]

Table 8-9: Elemental Phosphorus Market Share: FMC.

Products	Share of FMC's Phosphorus Product (1982) (%)	Share of Industry Market (1982) (%)
Acid Uses		
Builders and Water Treatment	62	38
Foods, Beverages, and Toothpaste	8	16
Metals Treating	4	14
Exports, Other	20	9
Non-Acid Uses	6	12
TOTAL	100	28

Table 8-10: FMC's Position in Phosphorus Markets -- 1984.

	Percent of Total Company P_4	Percent of Total U.S. Market P_4 Basis
Thermal Acid and Derivative Products	90	35
Non-Acid Uses		
PCL_3	3	18
P_2S_5	4	24-26
P_2O_5	-	-
Sodium Hypophosphate	-	-
Export, Other	3	10
TOTAL	100	32[a/]

[a/] Estimated company share of total U.S. elemental phosphorus market.

Source: [SRI86]

end of 1986, Chesebrough-Pond's was acquired by Unilever, Ltd., a $24 billion per year Dutch-British conglomerate. In July 1987, Imperial Chemical Industries, PLC, bought Stauffer Chemical from Unilever for $1.69 billion in cash. Finally, in September, 1987, Rhône-Poulenc, S.A. of France, acquired Stauffer's inorganic chemicals businesses, which had sales of $540 million and employed 3,600 people in 1986, from Imperial Chemical Industries for $522 million. This acquisition made Rhône-Poulenc the biggest producer of specialty phosphates and regenerated sulfuric acids in the world.

The most recent publicly available information on Rhône-Poulenc's P_4 operations was published by SRI International in February 1986. At that time, these operations belonged to Stauffer. Therefore, the following presentation of company data is presented using Stauffer's name. It is worth noting that Rhône-Poulenc also purchased the name Stauffer. Both plants continue to use the Stauffer name.

The third largest American producer of elemental phosphorus is Stauffer Chemical Company, with two plants and an annual capacity of 87,000 tons. Stauffer's Mt. Pleasant, Tennessee plant has five furnaces and capacity of 45,000 tons per year. The Silver bow, Montana plant has two furnaces and capacity of 42,000 tons per year.

The source of phosphate rock for Stauffer's Tennessee plant is the company's Globe mine in Mt. Pleasant, which is operated at about 0.4 to 0.5 million metric tons per year of ore and, in 1985, had reserves for 10-15 years of elemental phosphorus production. The sources of rock for the Montana plant are mines in Wooley Valley, Idaho, Wyoming, and Utah. The first is the primary source, with 45 million metric tons of reserves in 1980. All rock mined by Stauffer in Tennessee is used to produce elemental phosphorus. A portion of the rock mined in the western states is sold to other users, possibly to phosphate producers in Canada [SRI86].

Stauffer is considered the second most diverse producer of elemental phosphorus. In the early 1970s when environmental concerns were mounting, Stauffer turned its focus away from the laundry detergent market to produce phosphorus compounds for end-use areas that at the time were more highly valued. One such product is chlorinated trisodium phosphate, a cleanser and bacteriocide used in dishwashing compounds and metal cleaners. The company is expected to continue its focus on these areas, plus food uses and miscellaneous phosphorus chemicals. The market position of Stauffer in each end-use area is indicated in Table 8-11 and 8-12 [SRI83]. In 1986, the value of production

Table 8-11: Elemental Phosphorus Market Share: Stauffer.

Products	Share of Stauffer's Phosphorus Product (1982) (%)	Share of Industry Market (1982) (%)
Acid Uses		
Builders and Water Treatment	Neg.	Neg.
Foods, Beverages, and Toothpaste	35	50
Metals Treating	3	8
Exports, Other	31	25
Non-Acid Uses	31	29
TOTAL	100	16

Table 8-12: Stauffer's Position in Phosphorus Markets -- 1984.

	Percent of Total Company P_4	Percent of Total U.S. Market P_4 Basis
Thermal Acid and Derivative Products	74	17
Non-Acid Uses		
PCL_3	7-8	27
P_2S_5	8-9	28-30
P_2O_5	2	50-52
Sodium Hypophosphate	24	35-40
Export, Other	6	12
TOTAL	100	18[a/]

[a/] Estimated company share of total U.S. elemental phosphorus market.

Source: [SRI86]

from Stauffer's elemental phosphorus plants was estimated to equal $109.4 million. This represents 1.3 percent of Rhône-Poulenc's total revenues of $8,107.8 million (Table 8-6).

8.2.2.4 Occidental Petroleum Corporation

The smallest producer of elemental phosphorus is Occidental Petroleum, with one three-furnace plant in Columbia, Tennessee. The annual capacity of the plant is 57,000 tons.

Occidental uses captive washed rock (61-62 percent BPL) obtained from a local mine where the company owns 2,300 acres of reserves. In 1980, the reserves were estimated at 8 to 10 million metric tons, with about 12 to 14 years of remaining life [SRI86].

Occidental's market has been dominated by builder phosphates manufactured at facilities in Texas and Indiana. Little change is expected in the next few years, though some decline in the company's position in phosphorus pentasulfide (P_2S_5) products has occurred due to the entry of FMC into this market. As of 1985, Occidental had ceased production of P_2S_5, but was tolling P_4 through another P_2S_5 producer to supply its customers. As these contracts expire, Occidental will phase out its P_2S_5 business. The position of Occidental in each end-use market is detailed in Tables 8-13 and 8-14 [SRI86].

In 1983, elemental phosphorus is estimated to have contributed $71.7 million to Occidental's total corporate revenues of $15,525.2 million, or 0.5 percent (Table 8-6). The company is known to have attempted to sell its industrial phosphate operations in the early 1980s, but has since renewed its power contract through 1993 [SRI86].

8.2.3 Competitive Products and Processes

Consumption of elemental phosphorus in detergents, the major end use of elemental phosphorus, has been affected significantly by the availability of substitutes. With the controls or bans on phosphates recently imposed in some states, and threat of regulation by others, detergent manufacturers have reformulated their products, replacing phosphorus with carbonates, silicates, citrates, zeolites, NTA and nitrilotriacetic acid. Sodium carbonate (soda ash) is used in markets that have completely banned phosphorus. Though relatively inexpensive, sodium carbonate is less effective in cleaning than sodium tripolyphosphate (STPP), sometimes leaving residues on fabrics and being

Table 8-13: Elemental Phosphorus Market Share: Occidental.

Products	Share of Occidental's (1982) (%)	Share of Industry Market (1982) (%)
Acid Uses		
Builders and Water Treatment	60	15
Foods, Beverages, and Toothpaste	Neg.	Neg.
Metals Treating	5	8
Exports, Other	23	14
Non-Acid Uses	12	10
TOTAL	100	14

Table 8-14: Occidental's Position in Phosphorus Markets -- 1984.

	Percent of Total Company P_4	Percent of Total U.S. Market P_4 Basis
Thermal Acid and Derivative Products	77-80	10-11
Non-Acid Uses		
PCL_3	4	8
P_2S_5	6	12
P_2O_5	2	20-22
Sodium Hypophosphate	2	40-45
Export, Other	8	4
TOTAL	100	11[a]

[a] Estimated company share of total U.S. elemental phosphorus market.

Source: [SRI86]

less thorough as a soil deflocculant. (FMC and Stauffer are among the producing firms). Citrates are another viable alternative. With their high solubility characteristics, citrates have become the major builder used in heavy-duty liquid laundry detergents. However, citrates may cake when prepared in powders and thus are not attractive substitutes in powder formulations.

A third product competing with STPP for use in detergents is zeolites, sodium aluminosilicates that soften water by ion exchange. Alone, zeolites are not as effective as STPP in cleaning, but are often combined with it to produce a builder system with lower phosphate content. Since 1978, zeolites have become commercially significant. The fourth challenge to STPP in detergents is NTA. In 1970, use of NTA as a builder was voluntarily suspended in response to an unpublished government report suggesting the compound was teratogenic. In 1980, EPA issued a statement that NTA posed no threat to human health. NTA is now considered among the most attractive alternatives to STPP.

Another source of competition for the elemental phosphorus industry is the phosphoric acid produced from phosphate rock through wet process methods. Wet process acid has historically been less pure than acid produced from elemental phosphorus (called thermal process acid). When thermal acid costs and prices were low, it was not economical for wet process acid producers to purify their product to compete with the thermal acid. However, the increasingly high costs and prices of thermal acid have opened some traditional markets to wet process acid manufacturers who can now produce comparably pure acids at a competitive price. For example, Olin Corporation, a wet acid producer, had a seven percent share of the market for phosphorus in detergents in 1984.

8.2.4 Economic and Financial Characteristics

The major economic and social factors affecting demand for phosphorus derivatives are population growth, GNP growth, and to a lesser extent, demand for certain durable goods.

The largest end use for elemental phosphorus, detergents, has historically grown about one percent per year, approximately equal to population growth. With the controls on phosphates imposed in some states and subsequent reformulation of detergents, this use declined in the 1970s. By 1981, demand appeared to have restabilized at a one percent per year growth rate [CEN81].

Demand for phosphorus in food and beverages has reached maturity and closely follows changes in GNP. Historically, the use of oil additives has grown at GNP rates or less. Uses in metal treating are more cyclical, fluctuating with demand for durable goods, especially automobiles [CEN84, CEN78].

8.2.4.1 Prices

Most (approximately 80 percent) elemental phosphorus is used captively to produce phosphoric acid and derivatives. The meaning of the price data available for elemental phosphorus is, therefore, somewhat ambiguous. Manufacturer and co-producer transfer values are considerably below the list price published by the manufacturers of 90 to 100 cents per pound.

Table 8-15 compares the published list price and the actual average trading price for P_4 from 1960 to 1984. In 1983 and 1984, the list price is 30 percent higher than the average sales price. Because it is probably more representative of the real price, the average sales value has been used in the calculation of corporate elemental phosphorus revenues; an estimate of $0.75 per pound or $1500 per ton was selected.

Because the market for P_4 is a slow-growth market, and because most P_4 is sold captively within each company, it is expected that these prices, stable since 1983, will continue within the same range throughout the 1980s.

8.2.4.2 Employment

In 1987, approximately 1,820 persons were employed directly by the elemental phosphorus industry. Employment in each state is listed in Table 8-16. Estimated employment in each plant was listed in Table 8-3. Direct employment in the elemental phosphorus industry represents only a part of the employment that could be affected by a change in demand for elemental phosphorus. Others potentially affected would include phosphate rock miners and workers in other phosphorus chemical manufacturing facilities.

8.2.5 Outlook

Current forecasts for the elemental phosphorus industry indicate low growth and weak prospects for industry expansion. Major factors leading to the forecast are increasing costs of production,

Table 8-15: Average Price Range -- Phosphorus -- White. (Cents per Pound -- FOB Plant)

Price	1960	1965	1970	1975	1980	1982	1983	1984	1985	1986	1988
Trade List	19	19	19	53	80	80	90	91	91	91	91
Avg. Sales*	16	15	15	45	61	68	70				

* Average sales values include captive interplant transfers, no merchant market pricing.

Source: [MPC85]

Table 8-16: 1987 Employment by State for the Elemental Phosphorus Industry.

State	Number of Employees
Idaho	1,050
Tennesee	580
Montana	190

competition from substitutes, consumer and social trends, and lack of new uses for elemental phosphorus and its derivatives.

Changes in the cost of elemental phosphorus in recent years have been largely influenced by electricity costs, which have been increasing steadily and are expected to continue to increase. The increased cost of phosphorus and its derivatives has made substitutes more attractive. Substitutes in detergents, such as zeolites, NTA, and wet process phosphoric acid, are attractive both economically and because of environmental concerns and, in the case of zeolites and NTA, restrictions on phosphate use. Other uses of elemental phosphorus are deterred by substitutes and/or social factors. Phosphate-containing insecticides, a small market for the industry which had been growing at about 10 percent per year, face competition from non-phosphate insecticides. Uses in lubricating oils are increasing, but the lubricating oils are also lasting longer, offsetting the gains. Detergent uses resumed a slight upward trend in 1981-1984, but are still threatened by growth in consumer use of liquid detergents, trends toward lower washing temperatures, and use of zeolite builders in place of phosphates in formulas. As mentioned previously, bans on phosphates have been imposed, removed, and re-imposed in some states. Additional states may join New York, Indiana, Michigan, Wisconsin, Minnesota, Connecticut, and Maine in banning or controlling phosphates. In the past two years, the District of Columbia, Virginia, Maryland, and North Carolina have restricted phosphate use. South Carolina, Oregon and Illinois are considering phosphate bans. On the brighter side for detergent uses are the continued consumer demand for the new concentrated detergent powders, which have high concentrations of phosphates, and demand for phosphates in industrial detergents, which has been growing in the 1980s at 3 percent per year or greater [CEN84, CEN82].

8.3 Current Emissions, Risk Levels, and Feasible Control Methods

The Elemental Phosphorus Plant source category consists of eight facilities that produce elemental phosphorus by the electric furnace method. In 1988, five of these plants were operating, while three were not. These plants have been evaluated in previous EPA assessments under Section 112 of the Clean Air Act, and are subject to the NESHAP (40 CFR 61, Subpart K) promulgated on February 5, 1985. The NESHAP established an emissions limit of 21 Curies per year (Ci/yr.) for polonium-210 released from calciners and nodulizing kilns. This analysis examines alternative standards for emissions of radionuclides from calcining operations in the manufacture of elemental phosphorus.

Radionuclides of the uranium series, including polonium 210 (Po-210), lead (Pb-210), and uranium 238 (U-238), occur naturally in phosphate rock. The exhaust gases from phosphate rock nodulizing calciners at elemental phosphorus plants are considerably enriched with radionuclides because the Po-210 and Pb-210 volatize at the elevated temperatures in the calciner. As the exhaust gases cool, the radionuclides condense on the surface of mineral particulate matter or condense to form new particles. In the absence of adequate particulate controls, these emissions are vented to stacks for release to the atmosphere. The EPA conducted emission tests at several elemental phosphorus plants to characterize and quantify uncontrolled particulate and radionuclide emissions from the calciners and controlled emissions from the existing control systems.

Emissions of particulate matter and condensed radionuclides from these plants can be reduced by the application of modern particulate control technology. Presently, low pressure drop scrubbers are being used to reduce emissions of particulate matter from the nodulizing calciners. Emission control efficiencies for these low-pressure drop scrubbers are relatively low compared to those for high pressure drop scrubbers, wet electrostatic precipitators (ESP), or fabric filters (baghouses). These more efficient devices could potentially be used to control particulate and condensed radionuclide emissions from calciners at elemental phosphorus plants.

8.3.1 Current Emissions and Estimated Risk Levels

The following section includes a description of the elemental phosphorus production process, of existing effluent controls and of current radionuclide emissions. In addition, there is a brief examination of various technologies available for the control of these emissions as well as a presentation of the cost of purchasing, installing and maintaining them.

8.3.1.1 Process Description

Volume 2 of the *Environmental Impact Statement* [EPA89] and the supporting report on *Airborne Emission Control Technology* for the elemental phosphorus industry [SAI84] provide detailed data on each plant, including design, operation, source and radionuclide content of phosphate rock processed, and analyses of particulate and radionuclide emissions from various parts of the processing. Recently, Midwest Research Institute completed a study entitled, *Characterization and Control of Radionuclide Emissions from Elemental Phosphorus Production*, that updates the information contained in SAI84. These documents provide a more detailed discussion of the elemental phosphorus industry and are incorporated by reference.

Crushed and screened phosphate rock is fed into calciners and heated to the melting point, about 1300 degrees C. After calcining, the hot nodules are passed through coolers and into storage bins prior to being fed into electric furnaces, The furnace feed consists of the nodules, silica and coke.

Phosphorus and carbon monoxide (CO) are driven off as gases and vented near the top of the furnace. Furnace off-gases pass through dust collectors and then through water spray condensers where the phosphorus is cooled to the molten state. The mix of phosphorus and water (phossy water) and mud are then processed to recover the phosphorus. Clean off-gases from the condensers contain a high concentration of CO and are used as fuel in the calciners.

8.3.1.2 Existing Effluent Controls

Emissions from the calciners are typically controlled by low energy scrubbers. Since the 1984 assessment of this source category, one plant has upgraded its calciner emission controls by installing a high energy scrubber system. Emissions from nodule coolers, transfer points and furnace tap holes are controlled by either fabric filters or wet scrubbers. Screening plant emissions are usually controlled by fabric filters. Fugitive dust and radon gas emissions are not controlled.

8.3.1.3 Emissions

Through the period 1975 to 1980, EPA measured the radionuclide emission rates from three elemental phosphorus plants: FMC in Pocatello, Idaho [EPA77], Stauffer[1] in Silver Bow, Montana [An81a], and Monsanto in Columbia, Tennessee [An81b]. Measurements were made from release points representative of all major process operations in the production of elemental phosphorus.

All the emitted radionuclides are released as particulates except for radon-222, which is released as a gas. Essentially all the radon-222 and greater than 95 percent of the lead-210 and Po-210 emitted from these facilities are released from the calciner stacks. The high calcining temperatures volatize the Pb-210 and Po-210 from the phosphate rock, resulting in release of much greater quantities of these radionuclides than of the uranium, thorium and radium radionuclides. Analyses of doses and risks from these emissions show the emissions of Po-210 and, to a lesser degree emission of Pb-210 to be the major contributors to risk from radionuclide emissions from the elemental phosphorus plants.

---

[1] The Stauffer Chemical Company is currently owned by Rhône-Poulenc, S.A. Because Rhône-Poulenc also acquired the name, Stauffer, the company's elemental phosphorus plants have retained this name.

In 1983, EPA conducted extensive additional radionuclide testing at the FMC plant in Pocatello [EPA84c, Ra84a] and at the Stauffer plant in Silver Bow [EPA84d, Ra84b]. In early 1984, limited emission testing was done at the Monsanto plant in Soda Springs, Idaho [EPA84e, Ra84c]. This testing was limited to calciner off-gas streams and focused primarily on Pb-210 and Po-210 emissions in order to obtain additional information on these emissions and to obtain data on particle size distribution and lung clearance classification of these radionuclides in the calciner off-gases. Sampling of the calciner at Monsanto's Soda Springs plant was hampered by unavailability of suitable sampling locations. The major results of the testing are summarized in Table 8-17, which shows the estimated annual calciner emissions for the three plants studied.

Table 8-18 presents the estimated annual calciner emission rates for each of the eight elemental phosphorus plants. These values were used to estimate the radiation doses and fatal cancer risks from the plants.

The lung-clearance classifications and particle size distributions (AMAD) used in this assessment are the same as were used in the 1984 BID.

Table 8-19 shows the number of people living within 80 kilometers of these sites and the source of the meteorological data used in the calculations.

Table 8-20 gives estimates of the lifetime risk to the nearby individuals and the number of fatal cancers to the regional population. These data are taken from Volume 2 of the *Environmental Impact Statement*.

The total number of fatal cancers per year in the regional populations around elemental phosphorus plants is estimated at 0.077. The DARTAB computer code provides the frequency distribution of lifetime fatal cancer risks for each elemental phosphorus plant. It gives the number of people in each of a series of lifetime risk intervals and the number of cancer deaths that occur annually within each interval. This information is summarized in Tables 8-21 and 8-22 for operating and idle plants,

Table 8-17: Radionuclide Emissions from Calciners at Elemental Phosphorus Plants (1983-1984 Emission Test Results)

		Emissions (Ci/year)		
Plant	**Calciners**	**U-238**	**Pb-210**	**Po-210**
FMC - Pocatello, ID	2	0.004	0.12	8.60
Stauffer - Silver Bow, MT	2	0.0006	0.11	0.74
Monsanto-Soda Springs, ID*	1	0.006	5.60	21.00

SOURCE: [EPA89]

*Sampling at the Monsato - Soda Springs, ID plant was hampered by the unavailability of suitable sampling locations.

Table 8-18: Estimated Annual Radionuclide Emissions from Elemental Phosphorus Plants.

	Emissions (Ci/year)		
Plant	**U-238**	**Pb-210**	**Po-210**
OPERATING PLANTS			
FMC - Pocatello, ID	0.0032	0.14	10.0
Monsanto - Soda Springs, ID	0.0005	0.35	1.4
Stauffer - Silver Bow, MT	0.0006	0.11	0.74
Stauffer - Mt. Pleasant, TN	0.0003	0.058	0.28
Occidental - Columbia, TN	0.0001	0.064	0.31
IDLE PLANTS			
Monsanto - Columbia, TN	0.0020	0.41	0.64
Stauffer - FL	0.0035	0.19	0.15
Mobil - Pierce, FL	0.0016	0.012	0.013

SOURCE: [EPA89]

Table 8-19: Populations and Distances to the Maximum Exposed Individuals Around Elemental Phosphorus Plants.

Plant	Number of People within 80 km	Distance to Maximum Exposed Individual (m)	Source of Meteorological Data
OPERATING PLANTS			
FMC, Idaho	170,000	1,800	Pocatello, ID
Monsanto, Idaho	100,000	4,000	Soda Springs, ID
Stauffer, Montana	71,000	2,500	Butte, MT
Stauffer, Tennessee	560,000	1,500	Nashville, TN
Occidental, Tennessee	920,000	1,500	Nashville, TN
IDLE PLANTS			
Monsanto, Tennessee	900,000	1,500	Nashville, TN
Stauffer, Florida	1,700,000	2,500	Tampa, FL
Mobil, Florida	1,800,000	750	Orlando, FL

SOURCE: [EPA89]

Table 8-20: Fatal Cancer Risks from Radionuclide Emissions from Elemental Phosphorus Plants

Plant	Lifetime Risks to Nearby Individuals	Regional Populations (Fatal Cancers/yr Operatic
OPERATING PLANTS		
FMC - Pocatello, ID	0.0006	0.06
Monsanto - Soda Springs, ID	0.00008	0.003
Stauffer - Mt. Pleasant, TN	0.00003	0.003
Stauffer - Silver Bow, MT	0.00006	0.005
Occidental - Columbia, TN	0.00003	0.006
IDLE PLANTS		
Monsanto - Columbia, TN	0.00009	0.01
Stauffer - FL	0.00001	0.02
Mobil - Pierce, FL	0.00001	0.007

SOURCE: [EPA89]

Table 8-21: Distribution of Lifetime Fatal Cancer Risk in the Regional (0-80 km) Populations Around the Five Operating (1988) Elemental Phosphorus Plants

Risk Interval	No. of persons	Deaths/year
1 E+0 - 1 E-1	0	0.0
1 E-1 - 1 E-2	0	0.0
1 E-2 - 1 E-3	0	0.0
1 E-3 - 1 E-4	5,000	0.01
1 E-4 - 1 E-5	110,000	0.04
1 E-5 - 1 E-6	250,000	0.02
<1 E-6	1,500,000	0.005
TOTAL	1,800,000	0.08

SOURCE: [EPA89]

Table 8-22: Distribution of Lifetime Fatal Cancer Risk in the Regional (0-80 km) Populations Around the Three Idle (1988) Elemental Phosphorus Plants.

Risk Interval	No. of persons	Deaths/year
1 E+0 - 1 E-1	0	0.0
1 E-1 - 1 E-2	0	0.0
1 E-2 - 1 E-3	0	0.0
1 E-3 - 1 E-4	0	0.0
1 E-4 - 1 E-5	6,800	0.001
1 E-5 - 1 E-6	490,000	0.01
<1 E-6	3,900,000	0.02
TOTAL	4,400,000	0.03

SOURCE: [EPA89]

respectively. Data on the idle plants are included in unlikely case that a plant recommences operations. Risks for idle plants presented here will not occur unless one or more of these idle plants resumes operation. These data reflect the number of deaths expected to occur annually within the 0-80 km populations.

8.3.2 Control Technologies for Elemental Phosphorus Plants

The nodulizing kiln or calciner is by far the most significant source of Po-210 emissions from elemental phosphorus production. This section, based on information in MR188, describes and assesses control technologies that can be used to reduce those emissions. Generally Po-210 and Pb-210 are volatilized in the kiln or calciner and condense on the fine particles in the calciner particulate matter emission stream (PM stream). The control systems currently installed in the industry effectively collect large particles, but are not as effective in controlling fine particle emissions. Consequently, the technologies examined in this section are those that have been demonstrated to achieve high control efficiencies on fine particles.

Control of Po-210 and Pb-210 emissions is complicated by two factors. First, because the temperature of the flue gas leaving the kiln may be 400°C (750°F) or higher, significant concentrations of Po-210 can remain in the vapor phase. Second, the exhaust contains relatively high concentrations of SO_2 and HF· these acid gases can condense in the control system leading to subsequent corrosion and deterioration of performance. Mechanisms for cooling the exhaust gases and reducing the acid gas concentration in the gases are discussed in detail in MR188.

Four fine PM stream control techniques are examined in this study:

- wet electrostatic precipitators (wet ESP's)
- venturi scrubbers
- spray dryers with pulse jet fabric filters (SD/FF's)
- high efficiency particulate air (HEPA) filters

The wet ESP and venturi scrubber are the control systems used at operating elemental phosphorus plants. The SD/FF and HEPA filters were selected as high-efficiency PM control devices that have excellent potential for controlling Po-210 and Pb-210 emissions but that have not been applied to elemental phosphorus plants. The SD/FF systems have been applied successfully to combustion sources and mineral and metallurgical furnaces and have demonstrated high control efficiencies for condensible metals and acid gases. The HEPA filter has been demonstrated to achieve high control efficiencies on radionuclide emissions from uranium industry processes.

Four of the five operating elemental phosphorus facilities currently operate spray towers as either the primary control system or as a gas conditioning technique. These spray towers will remove coarse particulate matter as well as acid gases from the gas stream. All of the control techniques, except the SD/FF, can benefit from the reduced temperature, gas volume, and acid gas concentration that results from the installation of a spray tower upstream of the primary fine PM control device. Technical and engineering details on these control technologies are developed in MRI88.

8.3.3 Cost of Control Technologies

The capital and annualized costs for each of the applicable control devices were determined following the guidelines established in *Capital and Operating Costs of Selected Air Pollution Control Systems* (*GARD Manual*) [GARD78] and the *EAB Cost Control Manual* [EAB87]. These manuals were prepared for the U.S. Environmental Protection Agency (EPA) to provide technical assistance to regulatory agencies in estimating the cost of air pollution control systems. The costs in the GARD Manual are based on December 1977 costs; those in the *EAB Cost Control Manual*, on 1986 costs. The costs were adjusted to mid-1988 dollars using indices provided in *Chemical Engineering* and by the Bureau of Labor Statistics. Since the same basic procedure was used to cost each of the control techniques, a cost program was developed for use on a microcomputer. The paragraphs below describe the general cost methodology and key assumptions used to estimate the costs of the various control options. Detailed assumptions for each operating facility are presented in Appendices A through E of MRI88.

The costs were calculated assuming that each of the fine PM control measures, with the exception of the SD/FF, were added to control the exhaust from an existing spray tower. The existing system removes most of the large particles, quenches and cools the exhaust gas stream (thus, reducing gas volume and ensuring condensation of gaseous radionuclide emissions) and properly conditions the stream for treatment by the other options.

Capital costs include the direct and indirect costs to purchase and install the necessary ductwork, control device, fan systems, and stack. Direct capital costs include instruments, controls, taxes, freight, foundations, supports, erection and handling, electrical work, piping, insulation, painting, and site preparation. Indirect capital costs include engineering and supervision, construction and field expenses, construction fees, startup performance test, and contingencies. Table 4-4 in MRI88 presents the assumptions used for direct and indirect cost estimates based on information given in the *GARD Manual*. All ductwork was sized based on a gas velocity of 20 meters per second (m/s) (4,000 ft/min). Site-specific estimates of the length of additional ductwork to connect the existing control system with the add-on control device were developed for the analyses in Section 5. Stack diameters were calculated to provide a stack gas velocity of 18 m/s (3,600 ft/min). All stack heights are assumed to be 15 m (50 ft) for the add-on equipment. With the exception of connecting ductwork, no special retrofit costs were included in the cost analyses. Based on information collected during plant visits, MRI determined that no retrofit problems should be expected at the operating facilities.

Annualized costs include the total utility costs, the total operating labor costs, the total maintenance costs, the total overhead costs, the capital charges, and the total waste disposal costs. The annualized costs were based on 8,640 hours per year of operation (360 days)[2]. The utility costs reflect actual utility costs in the area of each facility as presented in Appendices A through E of MRI88. The operating and maintenance labor costs were determined using an average hourly wage of $12/hour(h). The operating labor hours per shift for each control device were 4 h/shift for SD/FF's, 2 h/shift for scrubbers, and 1 h/shift for ESP's. The maintenance labor was assumed to be 1 h/shift for ESP's and scrubbers and 2 h/shift for SD/FF's.

The quantity of sludge or dry waste collected by the add-on control devices was determined based on the efficiency of particulate removal. In the case of the SD/FF, the quantity of lime added to the system also is considered. The cost to dispose of the waste in a secured landfill was assumed to be $20/ton. The waste is considered to be hazardous for these calculations because of the concentration of radioactive material. (For comparison, it should be noted that the cost of disposing of nonhazardous wastes is approximately $5/ton.)

8.3.3.1 Venturi Scrubber Cost Assumptions

The capital and annualized costs for venturi scrubbers were based on procedures established in the GARD manual and on equipment costs established therein. Because of the large airflow encountered at most kilns, two identical scrubber systems in parallel were assumed on each kiln's exhaust stream. Radial fans were evaluated because of their ability to operate at high pressures and temperatures in an abrasive gas stream. The costs of the starter motor, direct and V-belt drives, and dampers are included in the fan costs. The corrosiveness (fluorides) of the gas stream entering a scrubber from the rotary kiln calciner requires that fabricated equipment cost estimates be based on the use of a combination of Hastelloy and Type 316 stainless steel. Plate thickness of the fan housing and ductwork was determined based on system static pressure. Details on the cost inputs for venturi scrubber control options for each facility are presented in Appendices A through E of [MRI88] for the individual facilities.

---

[2] The effect of this assumption is probably to overestimate the operating and maintenance costs *vis à vis* actual operating time. As was stated in section 8.2, it is assumed that the operating plants are producing for 7,400 hours (85 percent of capacity).

8.3.3.2 Wet ESP Cost Assumptions

Capital and annualized costs for the ESP were based on an EPA cost update. A primary factor that affects ESP costs is material of construction. The corrosiveness (fluorides) of the gas stream entering an ESP from the rotary kiln calciner requires that fabricated equipment, ductwork and ESP housing be constructed of a corrosion-resistant material. Costs for these components were based on the use of Type 316 stainless steel. Collecting electrodes also were assumed to be constructed from Type 316 stainless steel.

8.3.3.3 SD/FF Cost Assumptions

Spray dryer/fabric filter systems provide efficient collection of both condensible PM and acid gases. Key design parameters that affect system performance and costs are lime addition, gas temperature entering the FF, FF air-to-cloth ratio, and pressure drop through the system. Lime addition rates were calculated under the assumption of a 1.5:1 stoichiometric ratio of lime to HF and SO_2 combined. The gas temperature at the FF inlet was assumed to be 150°C (300°F). An air-to-cloth ratio of 1:1.2 m^2/m^3/min (4:1 ft^2/ft^3/min) and a system pressure drop of 3.1 kPa (12.5 in. w.c.) were used.

Total direct costs for the SD/FF unit were estimated on the basis of the cost equation:

$$C = 7.115\, Q^{0.517}$$

where:

C = total direct cost, $\$ \times 10^3$ in December 1987
Q = volumetric flow, acfm

This cost equation is based on comprehensive information collected by EPA as a part of the municipal waste combustion study. Vendors contacted during this study indicated that these costs would provide reasonable ±30 percent estimates.

8.3.3.4 HEPA Filter Cost Assumptions

Calciner gas stream characteristics that affect HEPA filter design and costs are moisture content, inorganic acid content, and loading in the gas stream to be treated. A spray tower is assumed to exist upstream of the HEPA filtration system; the high moisture content of the spray tower exit gases requires treatment of the gases by a de-mister and re-heater of the HEPA system. Because the exhaust gases are corrosive, Type 304 stainless steel housings and filter frames, acid-corrosion resistant filter media, and vinyl-clad aluminum separators are included in the cost of the system and replacement filters to provide the best available corrosion resistance. Because the PM loading in the gas stream exceeds the recommended maximum of 2.3 mg/m^3 (0.001 g/acf), the cost of a pre-filtration system is included in the total system cost. Estimated costs of the HEPA system, consisting of the pre-filters, HEPA filters, pre-filter/HEPA filter bank housing, de-mister, re-heater, and de-mister/reheater housing were obtained from equipment vendors.

A major operating cost for HEPA filters is filter replacement. The operating life of a HEPA depends on the increase in pressure drop resulting from particle collection within the filter media. A general guideline used to design filter systems is 4 lb/1,000 ft^3/min rated capacity (1.82 kg/1,000 ft^3/min). Filter life was estimated by assuming a HEPA capacity of 7.9 lb/1,000 ft^3/min (3.6 kg/1,000 ft^3/min) per filter based on vendor information. The methodology used to estimate filter life consisted of the following steps:

1. Obtain particle size distribution in spray tower exist gas stream from test data (where available);

2. Predict the mass of particles removed by pre-filtration using design pre-filter removal efficiencies for a given particle size;

3. Predict mass of particles removed by HEPA filter using filter design HEPA removal efficiencies;

4. Assume a filter capacity for HEPA filter and calculate HEPA filter operating life with and without use of a pre-filter;

5. Calculate pre-filter life as two times the HEPA filter life without the use of a pre-filter; and

6. Calculated HEPA filter life as the HEPA capacity divided by the particulate loading rate into the HEPA filter.

Estimates of the labor cost to replace pre-filters and HEPA filters as they are exhausted is based on 0.25 hours of labor per filter per replacement cycle. For example, filter replacement for a 36 filter bank requires 9 hours.

Exhausted filters are expected to exhibit increased concentrations of particulate matter containing Po-210 and Pb-210. To reduce the risk of inhalation of particles that may become airborne as a result of filter handling during the replacement process, an automatic bagout containment system is included in the system cost. Automatic bagout facilitates removal of exhausted filters without direct operator contact. Heavy duty PVC bags are installed inside the filter housing between the filters and the housing access door. When the door is opened, the bags form a barrier between the operator and the contaminated filter. By working through the bag, the operator can remove the filter and draw it into the bag without direct contact. The cost of replacement bags was included in the estimate of replacement material cost.

8.3.4 Emissions Control Alternatives

As outlined above, four fine PM control techniques were identified as having potential for control of Po-210 and Pb-210 emissions from calciners--venturi scrubbers, wet electrostatic precipitators (ESP's), spray dryers with pulse jet fabric filters (SD/FF's) and high energy particulate air (HEPA) filters. Ten different control alternatives based on these four technologies were examined. Four of the alternatives are based on venturi scrubbers at different pressure drops (P's), four are based on wet ESP's with different specific collecting areas (SCA's), and one each is based on a SD/FF system and a HEPA filter system. The paragraphs below describe the control alternatives and the assumptions that were used to assess performance and cost of these systems.

Four of the control alternatives comprise venturi scrubbers operated downstream from a spray tower. Four different pressure drops were examined--2.5 kPa (10 in. w.c.), 6.2 kPa (25 in. w.c.), 10 kPa (40 in. w.c.), and 20 kPa (80 in. w.c.). The values from 2.5 kPa to 10 kPa represent the range of P's for venturi scrubbers at recently installed control systems on elemental phosphorus plant calcining operations. The 20 kPa level was selected as a control alternative that is more stringent than the controls typically used in the industry, but that has been applied to other metallurgical processing facilities. Two other assumptions were made in evaluating the performance and costs of the venturi scrubber control alternatives. First, a spray tower was assumed to be used upstream from the venturi to control acid gases and condition the gas stream for the venturi. All of the operating facilities except FMC currently have a spray tower as a part of their control system that is assumed to be useable as the conditioning system for the venturi. Second, for all the venturi scrubber control alternatives, the L/G ratio was assumed to be 1.3 l/m^3 (10 gal/1,000 ft^3). This value was selected because it represents the upper end of the range typically found in venturi scrubber applications. A cyclonic mist eliminator also was assumed for all venturi scrubber alternatives. Note that although FMC does not have a spray tower in its systems, no tower was costed for this study. The low energy scrubber that FMC has in place as assumed to provide coarse PM control and gas conditioning.

The four ESP control alternatives that were considered comprised spray towers for acid gas control and gas stream conditioning followed by flat-plate wet ESP's. The four SCA levels that were considered were 39.4 $(m/s)^{-1}$ (200 ft^2/kacfm), 78.8 $(m/s)^{-1}$ (400 ft^2/kacfm), 118 $(m/s)^{-1}$ (600 ft^2/kacfm), and 158 (m/s)-1 (800 ft^2/kacfm). These four SCA levels are higher than the SCA at the one wet ESP that is applied to a nodulizing kiln. However, that unit is an older unit with relatively low PM removal efficiency. The range of 39.4 to 158 $(m/s)^{-1}$ (220 to 800 ft^3/kacfm) is representative of the SCA levels typically found on metallurgical and mineral processing facilities. The spray tower upstream from the ESP will remove acid gases from the gas stream and reduce the temperature to 65° to 70°C (150° to 160°F) to assure that the Po-210 and Pb-210 are condense before entering the ESP.

The ninth control alternative is the SD/FF control system. For this alternative, the exhaust stream is vented directly to the spray dryer without pretreatment. No SD/FF systems have been applied to elemental phosphorus facilities. However, they were selected as a stringent control technique because they have been demonstrated to control acid gases and condensation PM in other metallurgical and mineral processing operations such as aluminum reduction and glass manufacturing. Key assumptions made to estimate performance and cost are that sufficient moisture will be added to reduce gas temperature to 120°C (250°F) at the inlet to the FF, that lime will be added at a 1.5 stoichiometric ratio for HF and SO_2 combined, and that a pulse jet fabric filter capable of maintaining an outlet grain loading of 0.023 g/dscm (0.01 g/dscf) will be installed.

The final control alternative comprises a spray tower scrubber, a reheat system, a prefilter, and a HEPA filter in sequence. The spray tower is used to reduce the acid content of the gas stream and to remove larger sized PM. The reheat system is needed to raise the gas stream temperature sufficiently to prevent condensation of moisture and inorganic acids in the HEPA filter. The prefilter is used to reduce the PM loading to the HEPA filter and thereby extend its life. The HEPA filter system has not been applied to elemental phosphorus facilities and generally is not applied to furnaces that generate gas volumes as large as those generated by elemental phosphorus process calciners or nodulizing kilns. However, the system was selected for consideration because HEPA filters have been used successfully to control radionuclide emissions from uranium processing facilities and they do provide a much greater level of control than is provided by the other control alternatives.

8.3.5 Performance of Control Alternatives

The performance of each of the 10 control alternatives was calculated based on the reduction from baseline emissions that could be achieved by application of the control alternative. For each control alternative and each operating facility, annual emissions of Po-210 and Pb-210 were estimated using the procedures described in Section 4 of MRI88. The estimates of Po-210 and Pb-210 emission rates at the scrubber/ESP inlet, based on the assumptions that a spray tower is located upstream from primary control device are given in Table 8-23.

The estimate for FMC, Monsanto, and Stauffer, Montana, are based on tests conducted by EPA in 1983 and 1988 that measured emissions at the outlet of low-energy scrubbers at those facilities. Because the control systems at the two Tennessee plants consist of spray tower scrubbers, the emission estimates for those two facilities are based on the baseline emissions from those facilities. Separate estimates were developed for moving grate calciners (FMC) and rotary kilns (all other facilities).

Table 8-23: Estimated Po-210 and Pb-210 Emissions at the Scrubber/ESP Inlet

Facility	Po-210	Pb-210
FMC	10.00	0.14
Monsanto	30.00	9.50
Stauffer, MT	2.40	0.32
Stauffer, TN	0.28	0.058
Occidental	0.31	0.064

Control efficiencies also were developed for the SD/FF and the HEPA. The resultant efficiencies are 99.82 percent for rotary kilns and 99.85 percent for grate kilns. For the HEPA filter, the efficiency was assumed to be 99.998 percent as described above. Nationwide and plant specific capital and annualized cost summaries for each control alternative are presented in Tables 8-24 through 8-29. The estimated Po-210 removal efficiency of each control technology is also presented in these tables.

8.4 Analysis of Benefits and Costs

This section examines the benefits and the costs of alternative Po-210 standards for emissions from elemental phosphorus plants. Although Pb-210 emissions comprise an important part of total radionuclide emissions, the control of Pb-210 is similar to that of Po-210, therefore the following section refers only to the control of Po-210 emissions. It is assumed that Pb-210 emissions are reduced in proportion to Po-210 emissions.

8.4.1 Benefits of Po-210 Emissions Control

The health benefits that accrue to society over time from the control of Po-210 emissions at the elemental phosphorus plants consist largely of the reduction in expected lung cancers and, to a lesser

Table 8-24: Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal: Industry Totals

Control Alternative	Capital Costs\a (1988 $, mil)	Total Annualized Costs (1988 $, mil)
Wet Scrubber		
P = 2.5 kPa	9.42	2.90
P = 6.2 kPa	12.19	4.50
P = 10 kPa	16.08	5.20
P = 20 kPa	28.50	11.00
ESP		
SCA = 39.4 (m/s)-1	20.66	5.70
SCA = 78.8 (m/s)-1	29.70	7.70
SCA = 118 (m/s)-1	51.80	9.60
SCA = 158 (m/s)-1	63.99	12.00
Spray Dryer/ Fabric Filter	51.89	26.00
HEPA Filter	10.32	47.00

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air

\a Capital costs include primary equipment cost as well as auxiliary equipment costs, ductwork, fan systems, stacks, waste disposal, and installation.

SOURCE: [MRI88]

Table 8-25: Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at FMC's Pocatello, Idaho, Plant.

Control Alternative	Po-210 Removal Efficiency	Capital Costs\a (1988 $, mil)	Total Annualized Costs (1988 $, mil)
Wet Scrubber			
P = 2.5 kPa	20.0%	5.94	1.60
P = 6.2 kPa	60.0%	7.81	2.11
P = 10 kPa	80.0%	8.50	2.43
P = 20 kPa	90.0%	13.28	3.75
ESP			
SCA = 39.4 (m/s)-1	71.0%	10.64	2.01
SCA = 78.8 (m/s)-1	90.0%	15.50	2.84
SCA = 118 (m/s)-1	96.2%	20.28	3.65
SCA = 158 (m/s)-1	98.6%	24.79	4.43
Spray Dryer/ Fabric Filter	99.6%	17.33	9.70
HEPA Filter	99.998%	4.20	10.14

NOTES:
kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air

\a Capital costs include primary equipment cost as well as auxiliary equipment costs, ductwork, fan systems, stacks, waste disposal, and installation.

SOURCE: [MRI88]

Table 8-26: Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at Monsanto's Soda Springs, Idaho, Plant.

Control Alternative	Po-210 Removal Efficiency	Capital Costs\a (1988 $, mil)	Total Annualized Costs (1988 $, mil)
Wet Scrubber			
P = 2.5 kPa	20.0%	\b	\b
P = 6.2 kPa	55.0%	\b	\b
P = 10 kPa	90.0%	\b	\b
P = 20 kPa	95.0%	\b	\b
ESP			
SCA = 39.4 (m/s)-1	75.3%	\b	\b
SCA = 78.8 (m/s)-1	91.0%	\b	\b
SCA = 118 (m/s)-1	97.2%	12.89	2.33
SCA = 158 (m/s)-1	99.0%	15.72	2.82
Spray Dryer/ Fabric Filter	99.5%	10.38	5.43
HEPA Filter	99.998%	2.87	15.70

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air

\a Capital costs include primary equipment cost as well as auxiliary equipment costs, ductwork, fan systems, stacks, waste disposal, and installation.

\b No costs are incurred for this alternative because facility has more efficient control in place.

SOURCE: [MRI88]

Table 8-27: Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at the Stauffer Mount Pleasant, Tennessee, Plant.

Control Alternative	Po-210 Removal Efficiency	Capital Costs\a (1988 $, mil)	Total Annualized Costs (1988 $, mil)
Wet Scrubber			
P = 2.5 kPa	20.0%	1.46	0.59
P = 6.2 kPa	55.0%	1.87	0.75
P = 10 kPa	90.0%	2.46	0.93
P = 20 kPa	95.0%	5.23	1.61
ESP			
SCA = 39.4 (m/s)-1	75.0%	3.14	0.64
SCA = 78.8 (m/s)-1	92.9%	4.39	0.85
SCA = 118 (m/s)-1	96.4%	5.95	1.12
SCA = 158 (m/s)-1	96.4%	7.39	1.37
Spray Dryer/ Fabric Filter	99.6%	6.58	3.12
HEPA Filter	99.998%	1.02	7.45

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air

\a Capital costs include primary equipment cost as well as auxiliary equipment costs, ductwork, fan systems, stacks, waste disposal, and installation.

Table 8-28: Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at the Stauffer Silver Bow, Montana, Plant.

Control Alternative	Po-210 Removal Efficiency	Capital Costs\a (1988 $, mil)	Total Annualized Costs (1988 $, mil)
Wet Scrubber			
P = 2.5 kPa	20.0%	\b	\b
P = 6.2 kPa	55.0%	\b	\b
P = 10 kPa	90.0%	1.89	0.74
P = 20 kPa	95.0%	3.87	1.11
ESP			
SCA = 39.4 (m/s)-1	75.4%	2.35	0.79
SCA = 78.8 (m/s)-1	92.1%	3.31	0.83
SCA = 118 (m/s)-1	97.1%	4.08	0.87
SCA = 158 (m/s)-1	99.2%	4.75	0.91
Spray Dryer/ Fabric Filter	99.5%	7.54	3.07
HEPA Filter	99.998%	0.62	2.96

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air

\a Capital costs include primary equipment cost as well as auxiliary equipment costs, ductwork, fan systems, stacks, waste disposal, and installation.

\b No costs are incurred for this alternative because facility has more efficient control in place.

Table 8-29: Cost of Alternative Control Systems and Efficiency of Polonium-210 Removal at Occidental's Columbia, Tennessee, Plant.

Control Alternative	Po-210 Removal Efficiency	Capital Costs\a (1988 $, mil)	Total Annualized Costs (1988 $, mil)
Wet Scrubber			
P = 2.5 kPa	20.0%	2.02	0.74
P = 6.2 kPa	55.0%	2.51	0.92
P = 10 kPa	90.0%	3.23	1.15
P = 20 kPa	95.0%	6.12	1.91
ESP			
SCA = 39.4 (m/s)-1	74.2%	4.53	0.97
SCA = 78.8 (m/s)-1	93.6%	6.50	1.32
SCA = 118 (m/s)-1	96.8%	8.60	1.67
SCA = 158 (m/s)-1	96.8%	11.34	2.03
Spray Dryer/ Fabric Filter	99.4%	10.06	4.63
HEPA Filter	99.998%	1.61	10.07

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air

\a Capital costs include primary equipment cost as well as auxiliary equipment costs, ductwork, fan systems, stacks, waste disposal, and installation.

SOURCE: [MRI88]

extent, the reduction in non-hazardous particulate emissions near the site. The health benefits associated with the reduction of Po-210 emissions are determined to be the major component of the total health benefits due to any reduction of emissions at these plants. The efficiency of the particulate control technologies in terms of Po-210 removal and control is, therefore, of great importance in the calculation of the expected health benefits under alternative control scenarios.

Tables 8-24 through 8-29 presented the estimated efficiencies of Po-210 control of the various control alternatives. In this section, the expected benefits of the proposed alternate standards are estimated by applying proportionate reductions to the estimated health risks currently generated in the population residing within 80 km of the five operating plants. This method assumes a proportionate reduction in fatal cancers for given statutory reductions in Po-210 emissions. The proportionate reduction assumption is consistent with AIRDOS computer code procedures for evaluating population exposures in the affected areas and with the RADRISK code for translating exposures into expected fatal cancers, based on the linear dose-response model.

The results of analyses to determine the efficiencies of various alternatives for controlling the polonium-210 and lead-210 emissions from calciner off-gas systems at the five operating elemental phosphorus plants are summarized in Table 8-30. As described above, the control alternatives considered were the installation of wet (Venturi) scrubbers, electrostatic precipitators (ESP), a spray dryer followed downstream by a fabric filter (SD/FF), and high efficiency particulate air (HEPA) filters. The table presents the reduction in emissions that would result from the installation of the ten different control technologies on each of the operating plants. As discussed above, baseline emissions were estimated for each operating plant under the assumption that low-energy or spray scrubbers were present at each plant. The emissions reductions are estimated assuming that additional systems are added to these wet scrubbers. For the Spray Dryer/Fabric Filter system, the estimates are determined by first removing the low energy wet scrubber (the baseline emissions are divided by 0.35) and adding the SD/FF.

Lifetime risks to nearby individuals and incidences of fatal cancers per year in the regional populations were presented in Table 8-20. Table 8-31 and Table 8-31a present the benefits of the installation of the various emission control technologies in terms of fatal cancer risk. Table 8-31 presents total risk figures for each plant and for each control technology. Table 8-31a estimates the

Table 8-30: Estimated Po-210 Emission Levels Achieved by Control Alternatives.

Control	Emission Levels (Ci/year)				
Control	FMC	Monsanto	Stauffer	Stauffer	Occidental
Alternative	Idaho	Idaho	Montana	Tennessee	Tennessee
Baseline (*)	10.000	30.000	2.400	0.280	0.310
Wet Scrubber					
P = 2.5 kPa	8.000	21.000	1.700	0.200	0.220
P = 6.2 kPa	4.000	14.000	1.100	0.130	0.140
P = 10 kPa	2.000	3.000	0.240	0.028	0.031
P = 20 kPa	1.000	1.500	0.120	0.014	0.016
ESP					
SCA = 39.4 (m/s)-1	2.900	7.400	0.590	0.070	0.080
SCA = 78.8 (m/s)-1	1.000	2.700	0.190	0.020	0.020
SCA = 118 (m/s)-1	0.380	0.840	0.070	0.010	0.010
SCA = 158 (m/s)-1	0.140	0.290	0.020	0.010	0.010
Spray Dryer/ Fabric Filter	0.043	0.150	0.012	0.001	0.002
HEPA Filter	0.001	0.001	0.001	0.001	0.001

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air
(*) Emissions with low energy or spray scrubber. Additional systems are added to these wet scrubbers except with the Spray Dryer/ Fabric Filter control alternative.

SOURCE: [MRI88]

Table 8-31: Fatal Cancer Risks from Radionuclide Emissions from Elemental Phosphorus Plants and Risk Reductions from Alternate Control Technologies

Control	FMC - Idaho		Monsanto - Idaho		Occidental - Tennessee		Stauffer - Montana		Stauffer - Tennessee		TOTAL
Alternative	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Regional Populations (Cancers/ Year)
Current Risks	6.0E-04	6.0E-02	8.0E-05	3.0E-03	3.0E-05	6.0E-03	6.0E-05	5.0E-03	3.0E-05	3.0E-03	7.7E-02
Wet Scrubber											
P = 2.5 kPa	4.8E-04	4.8E-02	a	a	2.1E-05	4.3E-03	a	a	2.1E-05	2.1E-03	5.4E-02
P = 6.2 kPa	2.4E-04	2.4E-02	a	a	1.4E-05	2.8E-03	a	a	1.4E-05	1.4E-03	2.8E-02
P = 10 kPa	1.2E-04	1.2E-02	a	a	3.0E-06	6.0E-04	1.9E-05	1.6E-03	3.0E-06	3.0E-04	1.5E-02
P = 20 kPa	6.0E-05	6.0E-03	a	a	1.5E-06	3.0E-04	9.7E-06	8.1E-04	1.5E-06	1.5E-04	7.3E-03
ESP											
SCA = 39.4 (m/s)-1	1.7E-04	1.7E-02	a	a	7.5E-06	1.5E-03	4.8E-05	4.0E-03	7.7E-06	7.7E-04	2.4E-02
SCA = 78.8 (m/s)-1	6.0E-05	6.0E-03	a	a	2.1E-06	4.3E-04	1.5E-05	1.3E-03	1.9E-06	1.9E-04	7.9E-03
SCA = 118 (m/s)-1	2.3E-05	2.3E-03	4.8E-05	1.8E-03	1.1E-06	2.1E-04	5.7E-06	4.7E-04	9.7E-07	9.7E-05	4.9E-03
SCA = 158 (m/s)-1	8.4E-06	8.4E-04	1.7E-05	6.2E-04	1.1E-06	2.1E-04	1.6E-06	1.4E-04	9.7E-07	9.7E-05	1.9E-03
Spray Dryer/ Fabric Filter	2.6E-06	2.6E-04	8.6E-06	3.2E-04	1.1E-07	2.1E-05	9.7E-07	8.1E-05	1.9E-07	1.9E-05	7.0E-04
HEPA Filter	6.0E-08	6.0E-06	5.7E-08	2.1E-06	1.1E-07	2.1E-05	8.1E-08	6.8E-06	9.7E-08	9.7E-06	4.6E-05

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air
(a) Current Emissions result in risks lower than those obtainable with this control method.

SOURCE: [MRI88]

Table 8-31a: Reduction in Fatal Cancer Risks to Nearby Individuals and to Regional Populations for each Alternate Control Technology

Control Alternative	FMC - Idaho		Monsanto - Idaho		Occidental - Tennessee		Stauffer - Montana		Stauffer - Tennessee		TOTAL
	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Lifetime Risks to Nearby Individuals	Regional Populations (Cancers/ Year)	Regional Populations (Cancers/ Year)
Baseline	6.0E-04	6.0E-02	8.0E-05	3.0E-03	3.0E-05	6.0E-03	6.0E-05	5.0E-03	3.0E-05	3.0E-03	7.7E-02
Wet Scrubber											
P = 2.5 kPa	1.2E-04	1.2E-02	a	a	8.6E-06	1.7E-03	a	a	8.7E-06	8.7E-04	1.5E-02
P = 6.2 kPa	3.6E-04	3.6E-02	a	a	1.6E-05	3.2E-03	a	a	1.6E-05	1.6E-03	4.1E-02
P = 10 kPa	4.8E-04	4.8E-02	a	a	2.7E-05	5.4E-03	4.1E-05	3.4E-03	2.7E-05	2.7E-03	5.9E-02
P = 20 kPa	5.4E-04	5.4E-02	a	a	2.9E-05	5.7E-03	5.0E-05	4.2E-03	2.8E-05	2.8E-03	6.7E-02
ESP											
SCA = 39.4 (m/s)-1	4.3E-04	4.3E-02	a	a	2.3E-05	4.5E-03	1.2E-05	1.0E-03	2.2E-05	2.2E-03	5.0E-02
SCA = 78.8 (m/s)-1	5.4E-04	5.4E-02	a	a	2.8E-05	5.6E-03	4.5E-05	3.7E-03	2.8E-05	2.8E-03	6.6E-02
SCA = 118 (m/s)-1	5.8E-04	5.8E-02	3.2E-05	1.2E-03	2.9E-05	5.8E-03	5.4E-05	4.5E-03	2.9E-05	2.9E-03	7.2E-02
SCA = 158 (m/s)-1	5.9E-04	5.9E-02	6.3E-05	2.4E-03	2.9E-05	5.8E-03	5.8E-05	4.9E-03	2.9E-05	2.9E-03	7.5E-02
Spray Dryer/ Fabric Filter	6.0E-04	6.0E-02	7.1E-05	2.7E-03	3.0E-05	6.0E-03	5.9E-05	4.9E-03	3.0E-05	3.0E-03	7.6E-02
HEPA Filter	6.0E-04	6.0E-02	8.0E-05	3.0E-03	3.0E-05	6.0E-03	6.0E-05	5.0E-03	3.0E-05	3.0E-03	7.7E-02

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air
(a) Current Emissions result in risks lower than those obtainable with this control method.

SOURCE: [MRI88]

total reduction in risk due to each control alternative. The current risks at both the Monsanto plant and at the Stauffer, Montana, plant are lower than certain control technologies would allow.

As stated previously, both the baseline emissions rates and the risk estimates are discussed in detail in Volume 2 of the *Environmental Impact Statement*. The PM removal efficiency of each alternative control technology was estimated in MRI88.

8.4.2 Costs of Po-210 Emissions Control

The control technologies described above lead to a unique least-cost choice of technology to achieve a given level of emissions control for each of the five operating plants. These emissions levels and costs for each plant are presented in Tables 8-32 through 8-36.

The Po-210 removal efficiency of the SD/FF and the ESP's was derived by dividing the emission levels achieved by each alternative control technology by the baseline emissions for each technology. Removal efficiency for the scrubbers and for the HEPA filter are taken from MRI88. In Tables 8-32 through 8-36, the removal efficiency is applied to three Po-210 emissions scenarios: the baseline emission rate, the baseline rate plus a 10 percent safety margin, and the baseline rate plus a 25 percent safety margin. Emission reductions are then calculated for each control alternative using the appropriate Po-210 removal efficiency rate. Further sensitivity analysis could be conducted by allowing for specific measurement error and variability in the stated efficiencies.

Tables 8-32 to 8-36 also present the annualized costs of installing and operating the ten alternative control systems. The impact of these costs is then estimated both as a cost per ton of elemental phosphorus produced and as a percentage of the revenues derived from the production and sale of elemental phosphorus at each plant. As was stated in section 8.2, the cost per ton of P_4 is estimated to be $1,500. Revenues from the sale of this product are derived by assuming that the plants produce and sell 85 percent of estimated annual P_4 capacity at this price. Revenues would change if actual production varied from this estimate of 85 percent.

The cost of the control technologies varies by plant. For FMC cost ranges from $1.37 to $8.71 per ton of P_4 capacity, and from 0.92 to 5.81 percent of 1987 P_4 revenues. For Monsanto, the costs of those technologies which would improve current Po-210 emissions (1.4 Ci/y) range from $2.89 to

Table 8-32: Control Technology Costs and Estimated Po-210 Emission Rates at FMC's Pocatello, Idaho, Plant.

		Estimated Po-210 Emission Rate					
Control Alternative	Po-210 Removal Efficiency	No Safety Margin (Ci/y)	10 Percent Safety Margin (Ci/y)	25 Percent Safety Margin (Ci/y)	Total Annualized Control System Cost (mil $/yr)	Estimated Cost/Ton of P4 Produced (1987)	Percent of Value of 1987 P4 Revenues
Baseline Po-210 Emission Rate (*)		10.000	11.000	12.500			
Wet Scrubber							
P = 2.5 kPa	20.00%	8.000	8.800	10.000	1.60	$1.37	0.92%
P = 6.2 kPa	60.00%	4.000	4.400	5.000	2.11	$1.81	1.21%
P = 10 kPa	80.00%	2.000	2.200	2.500	2.43	$2.09	1.39%
P = 20 kPa	90.00%	1.000	1.100	1.250	3.75	$3.22	2.15%
ESP							
SCA = 39.4 (m/s)-1	71.00%	2.900	3.190	3.625	2.01	$1.73	1.15%
SCA = 78.8 (m/s)-1	90.00%	1.000	1.100	1.250	2.84	$2.44	1.63%
SCA = 118 (m/s)-1	96.20%	0.380	0.418	0.475	3.65	$3.13	2.09%
SCA = 158 (m/s)-1	98.60%	0.140	0.154	0.175	4.43	$3.80	2.54%
Spray Dryer/ Fabric Filter	99.57%	0.043	0.047	0.054	9.70	$8.33	5.55%
HEPA Filter	99.998%	0.0002	0.0002	0.0002	10.14	$8.71	5.81%

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air
(*) Emissions with low energy or spray scrubber. Additional systems are added to these wet scrubbers except with the Spray Dryer/ Fabric Filter control alternative.

SOURCE: [MRI88]

Table 8-33: Control Technology Costs and Estimated Po-210 Emission Rates at Monsanto's Soda Springs, Idaho, Plant.

		Estimated Po-210 Emission Rate (b)					
Control Alternative	Po-210 Removal Efficiency	No Safety Margin (Ci/y)	10 Percent Safety Margin (Ci/y)	25 Percent Safety Margin (Ci/y)	Total Annualized Control System Cost (mil $/yr)	Estimated Cost/Ton of P4 Produced (1987)	Percent of Value of 1987 P4 Revenues
Baseline Po-210 Emission Rate (*)		30.000	33.000	37.500			
Wet Scrubber							
P = 2.5 kPa	20.00%	24.000	26.400	30.000	a	a	a
P = 6.2 kPa	55.00%	13.500	14.850	16.875	a	a	a
P = 10 kPa	90.00%	3.000	3.300	3.750	a	a	a
P = 20 kPa	95.00%	1.500	1.650	1.875	a	a	a
ESP							
SCA = 39.4 (m/s)-1	75.33%	7.400	8.140	9.250	a	a	a
SCA = 78.8 (m/s)-1	91.00%	2.700	2.970	3.375	a	a	a
SCA = 118 (m/s)-1	97.20%	0.840	0.924	1.050	2.33	$2.89	1.92%
SCA = 158 (m/s)-1	99.03%	0.290	0.319	0.363	2.82	$3.49	2.33%
Spray Dryer/ Fabric Filter	99.50%	0.150	0.165	0.188	5.43	$6.72	4.48%
HEPA Filter	99.998%	0.0006	0.0007	0.0008	15.70	$19.44	12.96%

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air
(*) Emissions with low energy or spray scrubber. Additional systems are added to these wet scrubbers except with the Spray Dryer/ Fabric Filter control alternative.
(a) No costs are incurred for this alternative, because facility has more efficient control in place.
(b) Because the emissions at this facility are currently estimated at 1.4 Ci/y, higher estimates included in this table are theoretical.

SOURCE: [MRI88]

Table 8-34: Control Technology Costs and Estimated Po-210 Emission Rates at the Stauffer Mount Pleasant, Tennessee, Plant.

Control Alternative	Po-210 Removal Efficiency	Estimated Po-210 Emission Rate			Total	Estimated Percent of	
		No Safety Margin (Ci/y)	10 Percent Safety Margin (Ci/y)	25 Percent Safety Margin (Ci/y)	Annualized Control System Cost (mil $/yr)	Cost/Ton of P4 Produced (1987)	Value of 1987 P4 Revenues
Baseline Po-210 Emission Rate (*)		0.280	0.308	0.350			
Wet Scrubber							
P = 2.5 kPa	20.00%	0.224	0.246	0.280	0.59	$1.54	1.03%
P = 6.2 kPa	55.00%	0.126	0.139	0.158	0.75	$1.96	1.31%
P = 10 kPa	90.00%	0.028	0.031	0.035	0.93	$2.43	1.62%
P = 20 kPa	95.00%	0.014	0.015	0.018	1.61	$4.21	2.81%
ESP							
SCA = 39.4 (m/s)-1	75.00%	0.070	0.077	0.088	0.64	$1.67	1.12%
SCA = 78.8 (m/s)-1	92.86%	0.020	0.022	0.025	0.85	$2.22	1.48%
SCA = 118 (m/s)-1	96.43%	0.010	0.011	0.013	1.12	$2.93	1.95%
SCA = 158 (m/s)-1	96.43%	0.010	0.011	0.013	1.37	$3.58	2.39%
Spray Dryer/ Fabric Filter	99.64%	0.0010	0.0011	0.0012	3.12	$8.16	5.44%
HEPA Filter	99.998%	0.00001	0.00001	0.00001	7.45	$19.48	12.98%

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air
(*) Emissions with low energy or spray scrubber. Additional systems are added to these wet scrubbers except with the Spray Dryer/ Fabric Filter control alternative.

SOURCE: [MRI88]

Table 8-35: Control Technology Costs and Estimated Po-210 Emission Rates at the Stauffer Silver Bow, Montana, Plant.

Control Alternative	Po-210 Removal Efficiency	Estimated Po-210 Emission Rate (b)			Total Annualized Control System Cost (mil $/yr)	Estimated Cost/Ton of P4 Produced (1987)	Percent of Value of 1987 P4 Revenues
		No Safety Margin (Ci/y)	10 Percent Safety Margin (Ci/y)	25 Percent Safety Margin (Ci/y)			
Baseline Po-210 Emission Rate (*)		2.400	2.640	3.000			
Wet Scrubber							
P = 2.5 kPa	20.00%	1.920	2.112	2.400	a	a	a
P = 6.2 kPa	55.00%	1.080	1.188	1.350	a	a	a
P = 10 kPa	90.00%	0.240	0.264	0.300	0.74	$2.07	1.38%
P = 20 kPa	95.00%	0.120	0.132	0.150	1.11	$3.11	2.07%
ESP							
SCA = 39.4 (m/s)-1	75.42%	0.590	0.649	0.737	0.79	$2.21	1.48%
SCA = 78.8 (m/s)-1	92.08%	0.190	0.209	0.238	0.83	$2.32	1.55%
SCA = 118 (m/s)-1	97.08%	0.070	0.077	0.087	0.87	$2.44	1.62%
SCA = 158 (m/s)-1	99.17%	0.020	0.022	0.025	0.91	$2.55	1.70%
Spray Dryer/ Fabric Filter	99.50%	0.012	0.013	0.015	3.07	$8.60	5.73%
HEPA Filter	99.998%	0.00005	0.00005	0.00006	2.96	$8.29	5.53%

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air

(*) Emissions with low energy or spray scrubber. Additional systems are added to these wet scrubbers except with the Spray Dryer/ Fabric Filter control alternative.

(a) No costs are incurred for this alternative, because facility has more efficient control in place.

(b) Because the emissions at this facility are currently estimated at 1.4 Ci/y, higher estimates included in this table are theoretical.

SOURCE: [MRI88]

Table 8-36: Control Technology Costs and Estimated Po-210 Emission Rates at Occidental's Columbia, Tennessee, Plant.

Control Alternative	Po-210 Removal Efficiency	Estimated Po-210 Emission Rate			Total Annualized Control System Cost (mil $/yr)	Estimated Cost/Ton of P4 Produced (1987)	Percent of Value of 1987 P4 Revenues
		No Safety Margin (Ci/y)	10 Percent Safety Margin (Ci/y)	25 Percent Safety Margin (Ci/y)			
Baseline Po-210 Emission Rate (*)		0.310	0.341	0.388			
Wet Scrubber							
P = 2.5 kPa	20.00%	0.248	0.273	0.310	0.74	$1.53	1.02%
P = 6.2 kPa	55.00%	0.140	0.153	0.174	0.92	$1.90	1.27%
P = 10 kPa	90.00%	0.031	0.034	0.039	1.15	$2.37	1.58%
P = 20 kPa	95.00%	0.016	0.017	0.019	1.91	$3.94	2.63%
ESP							
SCA = 39.4 (m/s)-1	74.19%	0.080	0.088	0.100	0.97	$2.00	1.33%
SCA = 78.8 (m/s)-1	93.55%	0.020	0.022	0.025	1.32	$2.72	1.82%
SCA = 118 (m/s)-1	96.77%	0.010	0.011	0.013	1.67	$3.45	2.30%
SCA = 158 (m/s)-1	96.77%	0.010	0.011	0.013	2.03	$4.19	2.79%
Spray Dryer/ Fabric Filter	99.35%	0.0020	0.0022	0.0025	4.63	$9.56	6.37%
HEPA Filter	99.998%	0.00001	0.00001	0.00001	10.07	$20.78	13.86%

NOTES: kPa = kiloPascal
ESP = electrostatic precipitator
SCA = specific collection area
HEPA = high efficiency particulate air
(*) Emissions with low energy or spray scrubber. Additional systems are added to these wet scrubbers except with the Spray Dryer/ Fabric Filter control alternative.

SOURCE: [MRI88]

$19.44 per ton capacity, and from 1.92 to 12.96 percent of P_4 revenues. For Rhône-Poulenc, the costs range from $1.54 to $19.48 per ton capacity in Tennessee and from $2.07 to $8.60 per ton capacity in Montana. The control technology costs range from 1.03 to 12.98 percent of the Tennessee plant's 1987 P_4 revenues and from 1.38 to 5.73 percent of the Montana plant's revenues. The control technology costs at the Occidental plant in Columbia, Tennessee, demonstrate ranges similar to the other plants.

8.4.3 Estimates of Benefits and Costs.

Tables 8-37 through 8-41 present summaries of both the benefits and the costs of the control of Po-210 emissions on the five operating elemental phosphorus plants. For each of the plants, nine alternative emissions levels were examined, ranging from 10 Ci/y to 0.01 ci/y. A Po-210 emissions limit of 10 Ci/y represents a "no additional control" limit, as the highest current emissions rate at any plant is 10 Ci/y. No safety margin is assumed in these tables.

For each plant, the least-cost control method required to meet a given emissions level was chosen for presentation. The annualized cost for the least-cost technology is presented as is the emission limit that would be achieved by that technology, assuming no safety margin. Also presented in each table is the annual risk, in cancers per year, that would result from the installation of the least-cost technology.

The plant-by-plant analysis presented in Tables 8-37 through 8-41 is summarized, for all plants, in Tables 8-42 and 8-43. The first of these tables presents the total annualized costs of alternative emissions levels. Also presented is the increase in cost required to move from a given emissions level to a lower one. At an emissions rate of 10 Ci/y, there is no cost to the industry, as no additional emissions control is required. A cost of $2.4 million per year is experienced by the industry to meet an emissions level of 2 Ci/y. A further reduction to emissions of 1 Ci/y would increase cost to industry by $2.7 million. An emissions level of 0.01 Ci/y is estimated to cost $31.6 million per year.

Table 8-43 presents the total incidence and the incidence reduction achieved by alternative emissions levels. At a level of 10 Ci/y of Po-210, the total number of cancers per year remains unchanged, at an estimated 8E-02 per year (see Table 8-21). At an emissions level of 2.0 Ci/y, the incidence of cancer falls to 3E-02, a reduction of 5E-02 cancers per year. At 1.0 Ci/y, the annual incidence

Table 8-37: Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant

FMC - IDAHO

Emission Standard	Least-Cost Alter-native	Total Annualized Cost ($mil '88)	Annual Emissions Estimate (Curies)	Lifetime Risks to Nearby Individuals	Annual Risk (Cancers/ Year)
10.0 Ci/y	--	--	10.0	6E-04	0.0600
2.0 Ci/y	10 kPa	2.43	2.0	1E-04	0.0120
1.0 Ci/y	400 SCA	2.84	1.0	6E-05	0.0060
0.75 Ci/y	600 SCA	3.65	0.38	2E-05	0.0023
0.6 Ci/y	800 SCA	4.43	0.14	8E-06	0.0008
0.2 Ci/y	800 SCA	4.43	0.14	8E-06	0.0008
0.1 Ci/y	800 SCA	4.43	0.14	8E-06	0.0008
0.06 Ci/y	SD/FF	9.70	0.043	3E-06	0.0003
0.01 Ci/y	HEPA	10.14	0.0002	6E-08	0.00001

NOTES: 200 SCA = 39.4 (m/s)-1; 400 SCA = 78.8 (m/s)-1;
600 SCA = 118 (m/s)-1; 800 SCA = 158 (m/s)-1

SOURCE: [MRI88]

Table 8-38: Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant

MONSANTO - IDAHO

Emission Standard	Least-Cost Alter-native	Total Annualized Cost ($mil '88)	Annual Emissions Estimate (Curies)	Lifetime Risks to Nearby Individuals	Annual Risk (Cancers/ Year)
10.0 Ci/y	--	--	1.4	8E-05	0.003
2.0 Ci/y	--	--	1.4	8E-05	0.003
1.0 Ci/y	600 SCA	2.33	0.84	5E-05	0.00180
0.75 Ci/y	800 SCA	2.82	0.29	2E-05	0.00062
0.6 Ci/y	800 SCA	2.82	0.29	2E-05	0.00062
0.2 Ci/y	SD/FF	5.43	0.15	9E-06	0.00032
0.1 Ci/y	HEPA	15.7	0.0006	6E-08	0.0000021
0.06 Ci/y	HEPA	15.7	0.0006	6E-08	0.0000021
0.01 Ci/y	HEPA	15.7	0.0006	6E-08	0.0000021

NOTES: 200 SCA = 39.4 (m/s)-1; 400 SCA = 78.8 (m/s)-1;
600 SCA = 118 (m/s)-1; 800 SCA = 158 (m/s)-1

SOURCE: [MRI88]

Table 8-39: Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant

OCCIDENTAL - TENNESSEE

Emission Standard	Least-Cost Alter-native	Total Annualized Cost ($mil '88)	Annual Emissions Estimate (Curies)	Lifetime Risks to Nearby Individuals	Annual Risk (Cancers/ Year)
10.0 Ci/y	--	--	0.28	3E-05	0.006
2.0 Ci/y	--	--	0.28	3E-05	0.006
1.0 Ci/y	--	--	0.28	3E-05	0.006
0.75 Ci/y	--	--	0.28	3E-05	0.006
0.6 Ci/y	--	--	0.28	3E-05	0.006
0.2 Ci/y	200 SCA	0.64	0.07	8E-06	0.0015
0.1 Ci/y	200 SCA	0.64	0.07	8E-06	0.0015
0.06 Ci/y	400 SCA	0.85	0.02	2E-06	0.00043
0.01 Ci/y	600 SCA	1.12	0.01	1E-06	0.00021

NOTES: 200 SCA = 39.4 (m/s)-1; 400 SCA = 78.8 (m/s)-1;
600 SCA = 118 (m/s)-1; 800 SCA = 158 (m/s)-1

SOURCE: [MRI88]

Table 8-40: Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant

STAUFFER - MONTANA

Emission Standard	Least-Cost Alternative	Total Annualized Cost ($mil '88)	Annual Emissions Estimate (Curies)	Lifetime Risks to Nearby Individuals	Annual Risk (Cancers/ Year)
10.0 Ci/y	--	--	0.74	6E-05	0.005
2.0 Ci/y	--	--	0.74	6E-05	0.005
1.0 Ci/y	--	--	0.74	6E-05	0.005
0.75 Ci/y	--	--	0.74	6E-05	0.005
0.6 Ci/y	10 kPa	0.74	0.24	2E-05	0.0016
0.2 Ci/y	800 SCA	0.91	0.02	2E-06	0.00014
0.1 Ci/y	800 SCA	0.91	0.02	2E-06	0.00014
0.06 Ci/y	800 SCA	0.91	0.02	2E-06	0.00014
0.01 Ci/y	HEPA	2.96	0.00005	8E-08	0.0000068

NOTES: 200 SCA = 39.4 (m/s)-1; 400 SCA = 78.8 (m/s)-1;
600 SCA = 118 (m/s)-1; 800 SCA = 158 (m/s)-1

SOURCE: [MRI88]

Table 8-41: Least-Cost Control Alternatives Required to Meet Various Emissions Standards with Subsequent Emissions and Risks, by Plant

STAUFFER - TENNESSEE

Emission Standard	Least-Cost Alter-native	Total Annualized Cost ($mil '88)	Annual Emissions Estimate (Curies)	Lifetime Risks to Nearby Individuals	Annual Risk (Cancers/ Year)
10.0 Ci/y	--	--	0.31	3E-05	0.003
2.0 Ci/y	--	--	0.31	3E-05	0.003
1.0 Ci/y	--	--	0.31	3E-05	0.003
0.75 Ci/y	--	--	0.31	3E-05	0.003
0.6 Ci/y	--	--	0.31	3E-05	0.003
0.2 Ci/y	6.2 kPa	0.92	0.14	1E-05	0.0014
0.1 Ci/y	200 SCA	0.97	0.08	8E-06	0.00077
0.06 Ci/y	10 kPa	1.15	0.031	3E-06	0.0003
0.01 Ci/y	600 SCA	1.67	0.01	1E-06	0.000097

NOTES: 200 SCA = 39.4 (m/s)-1; 400 SCA = 78.8 (m/s)-1;
600 SCA = 118 (m/s)-1; 800 SCA = 158 (m/s)-1

SOURCE: [MRI88]

Table 8-42: Total Annualized Costs of Alternative Emissions Standards Sum of All Operating Plants.

Emission Standard	Total Annualized Cost ($mil '88)	Increase in Annualized Cost ($mil '88)
10.0 Ci/y	0.0	--
2.0 Ci/y	2.4	2.4
1.0 Ci/y	5.2	2.7
0.75 Ci/y	6.5	1.3
0.6 Ci/y	8.0	1.5
0.2 Ci/y	12.3	4.3
0.1 Ci/y	27.9	15.6
0.06 Ci/y	28.3	0.4
0.01 Ci/y	31.6	3.3

Table 8-43: Total Incidence with Alternative Emissions Standards Sum of All Operating Plants.

		Total Risk (Cancers per year	Reduction of Risk (Cancers per year)	Reduction of Risk From Baseline (Cancers per year)
10.0	Ci/y	8E-2	---	---
2.0	Ci/y	3E-2	5E-2	5E-2
1.0	Ci/y	2E-2	7E-3	6E-2
0.75	Ci/y	2E-2	5E-3	6E-2
0.6	Ci/y	1E-2	5E-3	7E-2
0.2	Ci/y	4E-3	8E-3	7E-2
0.1	Ci/y	3E-3	9E-4	7E-2
0.06	Ci/y	1E-3	2E-3	8E-2
0.01	Ci/y	3E-4	8E-4	8E-2

becomes 2E-02, a reduction from current levels of 6E-02 cancers per year. At a level of 0.01 Ci/y, the annual incidence falls to 3E-04, a reduction of 8E-02 cancers per year.

8.4.4 Alternatives for Ample Margin of Safety for Elemental Phosphorus Plants.

Table 8-44 presents the same benefit and cost information on an alternative-by-alternative basis rather than a plant-by-plant basis. For each alternative emission level, the least-cost control system, its annualized cost, the corresponding incidence and incidence reduction are presented. This information is shown for all plants as is the total cost and the total incidence. The change in cost from alternative to alternative is shown at the bottom of each section of the table. As in Tables 8-37 through 8-41, the emissions levels analyzed range from 10.0 Ci/y to 0.01 Ci/y.

Table 8-44a is a continuation of Table 8-44 involving a shift in emphasis from emissions to control technologies. Certain control technologies have been selected for analysis. As before, Alternative I is the "no additional control" alternative. As no new control equipment is required, there are no additional costs to the industry and no reduction in cancers per year.

Alternative X would require high energy scrubbers on the two largest plants and no further controls on the smallest plants. A large plant was defined as having a production capacity over 75,000 tons per year of elemental phosphorus, i.e., Monsanto and FMC. This alternative is identical to alternative II, which limited emissions to 2.0 Ci/y, with a cost to the industry of $2.43 million per year. The alternative would reduce incidence by 0.0569 cancers per year.

Alternative XI, requiring high energy scrubbers on all plants, would cost the industry an estimated $4.78 million per year. The incidence of cancer would be reduced by 0.06 cancers per year. Two other alternatives were examined, one requiring SD/FF on the two large plants and high energy scrubbers on small plants, and another requiring HEPA filters on the large plants and 600 SCA precipitators on the smaller ones. The costs and benefits of each are presented as Alternatives XII and XIII in Table 8-44a.

The results of the analysis of costs and benefits are summarized in section 8.1, the Introduction and Summary.

Table 8-44 : Alternatives for Ample Margin of Safety for Elemental Phosphorus Plants, According to Various Emissions Levels.

Plant	I. No Control (10 Ci/y)				II. Emissions (2 Ci/y)				III. Emissions (1 Ci/y)			
	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)
FMC - ID	--	--	6E-02	0	10 kPa	2.43	1E-02	5E-02	400 SCA	2.84	6E-03	5E-02
Monsanto - ID	--	--	3E-03	0	--	--	3E-03	0	600 SCA	2.33	2E-03	1E-03
Occidental - TN	--	--	6E-03	0	--	--	6E-03	0	--	--	6E-03	0
Stauffer - MT	--	--	5E-03	0	--	--	5E-03	0	--	--	5E-03	0
Stauffer - TN	--	--	3E-03	0	--	--	3E-03	0	--	--	3E-03	0
TOTAL		0.0	8E-02			2.43	3E-02	5E-02		5.17	2E-02	0
Incremental						2.43	5E-02			2.74	7E-03	

Incremental = the change in annualized cost and in cancer incidence from one alternative to the next.

Table 8-44 : Alternatives for Ample Margin of Safety for Elemental Phosphorus Plants, According to Various Emissions Levels.

	IV. Emissions (0.75 Ci/y)				V. Emissions (0.6 Ci/y)				VI. Emissions (0.2 Ci/y)			
Plant	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)
FMC - ID	600 SCA	3.65	2E-03	6E-02	800 SCA	4.43	8E-04	6E-02	800 SCA	4.43	8E-04	6E-02
Monsanto - ID	800 SCA	2.82	6E-04	2E-03	800 SCA	2.82	6E-04	2E-03	SD/FF	5.43	3E-04	3E-03
Occidental - TN	--	--	6E-03	0	--	--	6E-03	0E+00	200 SCA	0.64	2E-03	5E-03
Stauffer - MT	--	--	5E-03	0	10 kPa	0.74	2E-03	3E-03	800 SCA	0.91	1E-04	5E-03
Stauffer - TN	--	--	3E-03	0	--	--	3E-03	0E+00	6.2 kPa	0.92	1E-03	2E-03
TOTAL		6.47	2E-02	6E-02		7.99	1E-02	6E-02		12.33	4E-03	7E-02
Incremental		1.3	5E-03			1.52	5E-03			4.34	8E-03	

Incremental = the change in annualized cost and in cancer incidence from one alternative to the next.

Table 8-44 : Alternatives for Ample Margin of Safety for Elemental Phosphorus Plants, According to Various Emissions Levels.

	VII. Emissions (0.1 Ci/y)				VIII. Emissions (0.06 Ci/y)				IX. Emissions (0.01 Ci/y)			
Plant	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)
FMC - ID	SD/FF	9.7	8E-04	6E-02	SD/FF	9.7	3E-04	6E-02	HEPA	10.14	1E-05	6E-02
Monsanto - ID	HEPA	15.7	2E-06	3E-03	HEPA	15.7	2E-06	3E-03	HEPA	15.7	2E-06	3E-03
Occidental - TN	200 SCA	0.64	2E-03	5E-03	400 SCA	0.85	4E-04	6E-03	600 SCA	1.12	2E-04	6E-03
Stauffer - MT	800 SCA	0.91	1E-04	5E-03	800 SCA	0.91	1E-04	5E-03	HEPA	2.96	7E-06	5E-03
Stauffer - TN	200 SCA	0.97	8E-04	2E-03	10 kPa	1.15	3E-04	3E-03	600 SCA	1.67	1E-04	3E-03
TOTAL		27.92	3E-03	7E-02		28.31	1E-03	8E-02		31.59	3E-04	8E-02
Incremental		15.59	9E-04			0.39	2E-03			3.28	8E-04	

Incremental = the change in annualized cost and in cancer incidence from one alternative to the next.

Table 8-44a: Alternatives for Ample Margin of Safety for Elemental Phosphorus Plants, Using Different Control Technologies.

	I. No Control (10 Ci/y)				X. High-Energy Scrubbers on Large Plants No Further Controls on Small Plants				XI. High-Energy Scrubbers on All Plants			
Plant	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)
FMC - ID	--	--	6E-02	0	10 kPa	2.43	1E-02	5E-02	10 kPa	2.43	1E-02	5E-02
Monsanto - ID	--	--	3E-03	0	--	0	3E-03	0	--	--	3E-03	0E+00
Occidental - TN	--	--	6E-03	0	--	0	6E-03	0	6.2 kPa	0.75	3E-03	3E-03
Rhone-Poulenc - MT	--	--	5E-03	0	--	0	5E-03	0	6.2 kPa	0.68	2E-03	3E-03
Rhone-Poulenc - TN	--	--	3E-03	0	--	0	3E-03	0	6.2 kPa	0.92	1E-03	2E-03
TOTAL		0.0	8E-02	0		2.43	3E-02	5E-02		4.78	2E-02	6E-02
Incremental						2.43	5E-02			2.35	7E-03	

Incremental = the change in annualized cost and in cancer incidence from one alternative to the next.

Table 8-44a: Alternatives for Ample Margin of Safety for Elemental Phosphorus Plants, Using Different Control Technologies.

	XII. SD/FF on Large Plants 6.2 kPa on Small Plants				XIII. HEPA filters on Large Plants 600 SCA on Small Plants			
Plant	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)	Control System Choice	Annualized Cost ($mil '88)	Incidence (Cancers per Year)	Incidence Reduction (Cancers per Year)
FMC - ID	SD/FF	9.7	3E-04	6E-02	HEPA	10.14	1E-05	6E-02
Monsanto - ID	SD/FF	5.43	3E-04	3E-03	HEPA	15.7	2E-06	3E-03
Occidental - TN	6.2 kPa	0.75	3E-03	3E-03	600 SCA	1.12	2E-04	6E-03
Rhone-Poulenc - MT	6.2 kPa	0.68	2E-03	3E-03	600 SCA	0.87	5E-04	5E-03
Rhone-Poulenc - TN	6.2 kPa	0.92	1E-03	2E-03	600 SCA	1.67	1E-04	3E-03
TOTAL		17.48	7E-03	7E-02		29.50	8E-04	8E-02
Incremental		12.7	1E-02			12.02	6E-03	

Incremental = the change in annualized cost and in cancer incidence from one alternative to the next.

8.5 Economic Impact Analysis

Economic impacts occur when regulations alter the costs of production. Changes in the cost of production may lead to a change in product price and demand, thus altering the structure of the market in which the product is sold. The impacts on producers, consumers, workers and communities may be positive or negative, may depend on the overall state of the economy, and may be transitional or permanent. The impacts may represent losses in economic efficiency or they may be distributional, indicating shifts among economic entities (e.g., among firms or among groups of workers).

Government regulations generally occur when the market fails to meet all of the objectives of society. Regulations are designed to mend the market imperfections by, for example, internalizing to a polluter the cost of environmental damage caused by that pollution.

As shown in the previous sections of this chapter, limiting the allowable emissions of polonium-210 at various alternative levels below 10 Ci/y would require the five plants operating in 1988 to install and operate pollution control equipment designed to reduce its particulate emissions. The technology selected by the affected plant would depend on the level of standards and individual firm preferences. Varying levels and proportions of capital and operating expenses would be incurred based on the technology selected. These costs would result in an increase in the unit production cost of the affected facilities. The sum of these pollution control expenditures is referred to as the private real resource cost.

When a regulation imposes real resource costs on firms that change the unit cost of production, manufacturers will attempt to minimize the effect on profitability. This may result in attempts to reduce input costs including raw materials and wages, or to increase prices. If there is an increase in price, quantity demanded of the product may be reduced, and demand for competitors' output or substitute products may increase. These changes can lead to layoffs at the affected plant, reduced income in the community where the plant is located, and effects on the structure of the market. These effects on market structure include shifts in the price elasticity for the product, decreases in overall quantity demanded, and redistribution of market positions for each competitor and producer of substitute products.

The extent to which a regulated manufacturer may effectively pass on increases in cost will depend on the competitive environment in which the products are produced and sold and on the elasticity of demand. The elasticity of demand is a measure of the sensitivity of the consumers to changes in price. In some markets, a small change in price could lead to a large reduction in volume sold, while in other markets large price changes may have only marginal effects on volume. As a regulated manufacturer increases prices, quantity of the products demanded will usually fall. The rate at which volume falls will determine the change in total revenues that results from a change in price. If the market price of the product changes (all manufacturers incur higher costs), consumers use less of the product and some of the utility associated with consumption of the product will be lost. Consumers who continue to use the same amount of the product at higher prices will have to allocate a larger portion of their budgets to this consumption, thus reducing savings or consumption of other goods and services.

The control of Po-210 emissions through the setting of an emissions standard will result in changes in the cost of producing elemental phosphorus only if an emission standard lower than 10 Ci/y is chosen, according to the emissions data gathered during 1988 (see section 8.3). The structure of this industry and the nature of the market in which the output is utilized adds significant uncertainty to the measurement and allocation of expected economic impacts. Some of these characteristics include the following:

- The industry has contracted substantially over the past two decades, closing over half the plants and reducing capacity enormously.
- Elemental phosphorus is an intermediate product utilized to produce chemical compounds used in consumer goods that are sold in highly competitive markets (detergents, soft drinks, etc. - see section 8.2).
- All plants are owned by large, highly integrated Fortune 500 corporations that consume virtually all the P_4 output in company-owned chemical plants.
- The owners of the P_4 plants own or have extraction leases for phosphate rock, an exhaustible resource that is the principle input to production.
- The plant most likely to require new emissions control equipment is the largest plant, accounting for over one-third of industry capacity.

- The affected plant has among the lowest production costs due to economies of scale and regional differences in input prices.

- The long range prospects for current elemental phosphorus markets are uncertain, and extensive industry research and development efforts over the past fifteen years have failed to develop any significant new markets.

- Bans or restrictions on phosphate use in detergents have been imposed in some states.

These and other factors make it difficult to predict the ability or desirability of the regulated plant(s) to pass on all or part of these pollution control costs to consumers through price increases. In the next section, the costs of producing elemental phosphorus at the currently operating plants are compared. A subsequent section presents some methods for bounding the potential economic impacts of the proposed alternatives.

8.5.1 Production Costs

The primary components of the cost of producing elemental phosphorus are phosphate rock, coke, electricity and labor. Together, these account for 80 to 88 percent of the cost of producing a ton of phosphorus. Prices of these materials for each producer and plant vary, with the western plants having a significant cost advantage compared to Tennessee plants. The components of cost for elemental phosphorus and estimated costs for each plant are described in the following section.

8.5.1.1 Components of Cost

The inputs to elemental phosphorus production were investigated for a hypothetical Tennessee plant by Arthur D. Little [ADL73], and for FMC by EPA in 1984 [EPA84e]. Additional data on costs are published in SRI's *Chemical Economics Handbook*. The ranges in the amounts and prices of each input needed to produce a ton of phosphorus seen in these studies are provided in Table 8-45. Prices are indexed to June, 1988, dollars.

Table 8-45: Cost of Elemental Phosphorous

Cost Item	Units	Units/Ton of Phosphorus	Cost/Unit[1]	Cost/Ton of Phosphorus
RAW MATERIALS				
Phosphate Rock	tons	10-12.5	$12.35-$27.80	$123.5-$347.50
Silica	tons	0.79	13.22	10.44
Coke	tons	1.4-1.5	121.56	170.18-182.34
Electrodes	lbs	0.42	.79	.33
UTILITIES				
Electricity	kWh	13,000-15,200	0.0168-0.0485	218.4-737.2
Water	Mgal	20.00	.137	2.73
Fuel	MSCF	12.00	1.37	16.38
OTHER				
Labor	n.a.	n.a.	n.a.	204.67-275.74
Operating Supplies	n.a.	n.a.	n.a.	13.68
Maintenance	n.a.	n.a.	n.a.	136.96
Taxes	n.a.	n.a.	n.a.	30.81
Subtotal				928.08-1754.11
GS&A(10%)	n.a.	n.a.	n.a.	92.81-175.41
TOTAL COSTS	n.a.	n.a.	n.a.	1020.89-1929.52

[1] Indexed to June, 1988 prices

SOURCE: [EPA84b]

As the table shows, the total cost per ton could range from $1,021 to $1,930; however, it is unlikely that the variation in costs is this broad. The primary inputs to production and estimates of their cost for each plant are discussed below.

8.5.1.1.1 Phosphate Rock

Phosphate rock costs from $12.35 to $27.80 per ton, delivered. At the high end of the range is the beneficiated rock used by plants in Tennessee. When this higher quality rock is used, less rock may be required (10 tons of rock per ton of phosphorus, compared to 12.5 tons) [ADL73, EPA84e]. Lower grade material is usually less expensive, but the proximity and convenience of transporting the rock to the plant is the most important cost factor. Idaho rock is relatively low cost, because it is obtained from captive mines close to elemental phosphorus plants. Rhône-Poulenc's phosphate rock costs for its Montana plant are relatively high because of greater transportation costs [SRI83]. The estimated costs of phosphate rock for each plant and producer are summarized in Table 8-46.

8.5.1.1.2 Coke

For each ton of phosphorus produced, 1.4 to 1.5 tons of coke are required, depending on quality. The cost of the coke per ton to the producer depends on its quality, grade, and the value at which it is transferred when captively produced. The cost of coke per ton of phosphorus is levelled across producers by this cost and input structure: lower quality coke is lower-priced, but more is required, while higher quality coke is higher-priced, and less is required [SRI83]. The cost of coke per ton of phosphorus used in this analysis was estimated to range from $170.18 to $182.34. This cost assumes 1.42 tons of coke are used per ton of phosphorus[3] and that the price per ton is $121.56, the national average market price of coke [SRI83].

8.5.1.1.3 Electricity

Production of a ton of phosphorus requires 12,000 to 15,000 kWh of electricity. Estimates of the cost of this electricity range from $0.0168 to 0.0485 per kWh [SRI83].

---

[3] Unpublished EPA data.

Table 8-46: Costs of Phosphate Rock Used in Phosphorus Production

Producer	Location	Unit Cost $/Ton[1]	Tons of Phosphate Rock Mined/ Ton of Phosphorus	Phosphate Rock Cost $/Ton
Monsanto	Columbia, TN	27.70	10.00	277.00
	Soda Springs, ID	19.15	12.50	239.36
FMC	Pocatello, ID	19.15	12.50	239.36
Stauffer c	Mt. Pleasant, TN	27.70	10.00	277.00
	Silver Bow, MT	19.50	12.50	239.36
Occidental	Columbia, TN	27.70	10.00	277.00

[1] Indexed to June, 1988 prices.

SOURCE: [JFA86]

Plants served by TVA have witnessed steadily increasing rates since 1976, as rates have been more and more dependent on coal purchase commitments. Power rates in Idaho were stable until the last part of the 1970s, and for Montana until 1980. Rates are expected to continue to grow for FMC and Monsanto in Idaho because of increasing reliance on coal-fired electricity. Rhône-Poulenc, which was previously purchasing power from Bonneville, changed sources to Montana Power and Light in late 1982 in an effort to control costs [SRI83]. The estimated cost of electricity for each plant and producer is shown in Table 8-47.

8.5.1.1.4 Labor

The fourth major cost of producing phosphorus is labor. Average labor costs in the industry are estimated to range from $36,001 to $43,201 per year[4] per worker and labor costs per ton of phosphorus from $204.13 to $275.01[5]. Labor costs for each producer and plant are detailed in Table 8-48.

8.5.1.2 Total Costs per Plant

The cost of producing a ton of phosphorus is estimated to range from approximately $1,260 in Montana and Idaho, to over $1,700 in the Tennessee plants. These estimates are comparable to the estimates provided by SRI in the *Chemical Economics Handbook* of $1,070 to $1,180 per ton of phosphorus in the western states and $1,315 to $1,555 in Tennessee, when indexed to 1988 dollars. Costs by plant are summarized in Table 8-49.

8.5.2 Measuring Economic Impacts

The degree to which the elemental phosphorus industry will be affected by pollution control costs, and the ability of producers to mitigate these impacts through price changes will be determined by the market structure of the industry. As noted in sections 8.2 and 8.5.1, several alternative theories could be used to describe this market. First, the output of each plant in this industry is almost totally

---

[4] Industry information for 1983, updated to 1988 dollars.

[5] JFA estimates

Table 8-47: Costs of Electricity Used in Phosphorus Production

Producer	Location	Electricity Required KWH/Ton	Unit Cost of Electricity $/KWH	Cost of Electrictity $/Ton
Monsanto	Columbia, TN	13,000	0.0485	630.38
	Soda Springs, ID	13,000	0.0231	300.83
FMC	Pocatello, ID	13,000	0.0231	300.83
Stauffer	Mt. Pleasant, TN	13,000	0.0485	630.38
	Silver Bow, MT	13,000	0.0231	300.83
Occidental	Columbia, TN	13,000	0.0485	630.83

SOURCE: [JFA86]

Table 8-48: Labor Costs.

Plant	Location	Employees	$/Man Year	$(million)	Production(tons)[1]	$/Ton Phosphorus
Monsanto	Columbia, TN	440	39,878	17.55	63,800	275.01
	Soda Springs, ID	397	43,201	17.15	76,500	224.19
FMC	Pocatello, ID	600	39,878	23.93	106,300	225.09
Rhône-Poulenc	Mt. Pleasant, TN	305	36,001	10.97	42,500	258.35
	Silver Bow, MT	185	39,878	7.40	34,000	216.98
Occidental	Columbia, TN	275	36,001	9.89	48,500	204.13

[1] Production is estimated 1984 production.

SOURCE: [EPA84b]

Table 8-49: Summary of Cost Estimates, by Plant

Producer	Location	Phosphate Rock	Electricity	Labor	Coke	Subtotal	Other Costs	Total Excluding GS&A	Total Including GS&A at 10%
Monsanto	Columbia, TN	$277.01	$630.80	$275.02	$172.62	$1,355.45	$211.78	$1,567.23	$1,723.95
	Soda Springs, ID	$239.36	$301.46	$224.19	$172.62	$937.63	$211.78	$1,149.41	$1,264.35
FMC	Pocatello, ID	$239.36	$301.46	$225.09	$172.62	$938.53	$211.78	$1,150.31	$1,265.34
Rh ne-Poulenc	Mt. Pleasant, TN	$277.01	$630.80	$258.35	$172.62	$1,338.78	$211.78	$1,550.56	$1,705.62
	Silver Bow, MT	$239.36	$301.46	$216.39	$172.62	$929.83	$211.78	$1,141.61	$1,255.71
Occidental	Columbia, TN	$277.01	$630.80	$204.13	$172.62	$1,284.56	$211.78	$1,496.34	$1,645.97

consumed by other plants owned by the parent corporation. The downstream plants process this elemental phosphorus into various compounds of phosphorus that are sold as inputs to the production of highly-competitive goods. Substitute inputs for the phosphorus are available and widely used. Thus, the demand for elemental phosphorus is derived from the demand for products in highly-competitive, price-sensitive markets. Therefore, phosphorus producers may face a flat demand curve, as in a competitive market, even though there are only four producing companies. A flat or nearly-flat demand curve suggests that the manufacturer would have little opportunity to pass on increases in unit costs through price increases.

An alternative description of the elemental phosphorus industry is that it is an oligopoly with a strong price leadership. There are only four manufacturers, and production costs at the western plants are lower than at plants elsewhere. The low-cost manufacturers have the ability to set the market price at a profit-maximizing production level. The higher cost manufacturers would thus be price takers, because, if market price were set at the marginal cost of the low-cost producers, the higher-cost producers would have to sell their product at this price, even if it meant losing money on each unit sold, or leave the industry. As seven higher-cost plants have been closed over the past two decades, it would appear that the cost of closing these plants was less than the cost of selling products below their individual marginal cost of production.

A collusive oligopoly will attempt to operate as a monopoly, setting industry marginal revenue equal to industry marginal cost to determine output. The price is then established by the demand curve at a level above that which would exist in a competitive market. Thus, industry maximizes its profit. Output and revenue for each manufacturer are determined by the manufacturer's marginal costs and the price level. While it may not be possible in the absence of collusion for the oligopoly to operate in this fashion, firms in such an industry would likely be able to maintain price above marginal cost (the competitive price) and thus earn excess profits.

Firms in any market will determine their level of output based on their marginal cost. By definition, fixed costs do not vary with the level of output. Therefore, they do not enter into the production rate decision since firms in general will continue to produce as long as marginal revenue is greater than or equal to marginal cost. The cost of regulatory compliance presents a special case. While the expenditures for pollution control capital equipment are clearly fixed costs, operating costs for this equipment are not so clearly categorized. Usually, operating cost is thought of as a variable cost. That is, if no production occurs, no operating costs are accrued. However, in the case of these particular regulations of the elemental phosphorus industry, the capital and operating costs vary little with output. The assumption here is that any minimal costs required to meet a standard may be viewed as fixed costs, suggesting that no changes in output or price would be expected as a result of the compliance with the standards. In this case, all the impacts will be born by the affected manufacturer in the form of lower profits. If an emissions limit of 10 Ci/y is chosen, there would be no cost and no economic impact.

That phosphate rock is an exhaustible resource owned by the regulated industry requires some special consideration. The resource stock is an asset held by its owner, the value of which is determined by the size of the asset and the present value of the difference between market price and extraction cost in any period. The rate of extraction selected by the owner of the resource will depend on the structure of the market in which the resource is sold, forecasts of the future prices for the product, and forecasts of interest rates. If, for example, the resource owner expected the rate of growth in the net price (market price less extraction cost) to be less than the interest rate, that owner would extract the resource as quickly as possible and convert it to a new asset that would return at least the market rate of interest. In general, it would be expected that a monopolist would set prices high enough that the extraction rate would be slower than that of a producer in a competitive market. In an oligopoly, the resource would be extracted faster than in the monopoly, but slower than in the competitive market, either the price and extraction rates approaching the competitive case as the number of firms in the industry became larger. In this case, several stocks of the exhaustible resource are available with each plant being fed by a specific mine. The low-cost producer is able to earn a higher return from its resource than are the other plants. This higher return allows the low-cost producer to earn an economic rent on its stocks of phosphate rock. By imposing a new environmental cost that is mostly fixed cost, the available rent that could be earned by the low-cost producer is reduced by the amount of the pollution abatement costs.

While it is uncertain to what extent product prices and quantity demanded of elemental phosphorus will be affected by these standards, if an emissions level of 10 Ci/y is chosen, there will be no change in production levels at the regulated facility. It is assumed that the product price is unchanged. Therefore, there are no consumer impacts, no change in employment levels and no community impacts. The entire impact of the standard would be calculated as a reduction in profits for the affected firms. Table 8-50 presents the estimated value of elemental phosphorus production, the total revenue of the parent corporation, and the percent of total revenues accounted for by elemental phosphorus in 1986. In that year, Monsanto and FMC, the two firms potentially affected by the 1984

Table 8-50: Revenues from Elemental Phosphorus Production and Total Corporate Revenues (1986).

	Estimated Elemental Phosphorus Revenue[a] (in millions)	Total Corporate Revenue (in millions)	Elemental Phosphorus as a Percent of Total Revenue
FMC	$174.7	$3,078.9	5.7%
Monsanto	$121.1	$6,879.0	1.8%
Rhône-Poulenc	$110.9	$8,107.8	1.4%
Occidental	$72.7	$15,525.2	0.5%
TOTAL	$479.4	$33,590.9	1.4%

[a] Estimated revenue = estimated production x price
Estimated production = 85 percent of capacity
Price = $0.75 per pound or $1,500 per ton
Revenue for Rhône-Poulenc = 51,642 FF x $0.157/FF

regulation, had 1.8 and 5.7 percent of their revenues associated with elemental phosphorus production. In 1987, elemental phosphorus revenues accounted for an estimated 5.7 percent of FMC's total corporate revenues. Table 8-51 shows the level of capital expenditures normally undertaken by each firm, required capital expenditures under different regulatory alternatives and the percentage of total capital expenditures represented by the pollution control capital expenditures.

8.5.3 **Regulatory Flexibility Analysis**

The Regulatory Flexibility Act (RFA) requires regulators to determine whether proposed regulations would have a significant economic impact on a substantial number of small businesses or other small entities. If such impacts exist, regulators are required to consider specific alternative regulatory structures to minimize the small entity impacts without compromising the objective of the statute under which the rule is enacted. Alternatives specified for consideration by the RFA are tiering regulations, performance rather than design standards, and small firm exemptions.

The four firms operating plants in this industry are major diversified corporations, the smallest of which was ranked 131 on the *Fortune* list of the 500 largest U.S. companies in 1987. The Pocatello plant accounts for over one-third of national production and probably enjoys the lowest cost structure due to economies of scale and regional cost differences. It is unlikely that this situation will change after the imposition of a Po-210 standard. In light of the fact that the four smallest plants in the elemental phosphorus industry are expected to incur no compliance costs as a result of any regulatory alternatives under consideration, no significant small business impact will occur.

Table 8-51: Impact on Capital Expenditures.

Producer Costs	Capital Expenditures, 1986 (in millions)	Standard Option (Ci/Year)	Estimated Capital Costs of Emissions Control (in millions)	Emissions Costs as a Percent of 1986 Capital
Monsanto[1]	520.0	10.00	0.00	0.00
		2.00	0.00	0.00
		1.00	12.89	2.48
		0.75	15.72	3.02
		0.60	15.72	3.02
		0.20	10.38	2.00
		0.10	2.87	0.55
		0.06	2.87	0.55
		0.01	2.87	0.55
FMC	232.8	10.00	0.00	0.00
		2.00	8.50	3.65
		1.00	15.50	6.66
		0.75	20.28	8.71
		0.60	24.79	10.65
		0.20	24.79	10.65
		0.10	17.33	7.44
		0.06	17.33	7.44
		0.01	4.20	1.80
Rhône-Poulenc[2]	797.3	10.00	0.00	0.00
		2.00	0.00	0.00
		1.00	0.00	0.00
		0.75	0.00	0.00
		0.60	1.89	0.24
		0.20	7.89	0.99
		0.10	7.89	0.99
		0.06	9.14	1.15
		0.01	6.57	0.82

Table 8-51 (contd): Impact on Capital Expenditures.

Producer Costs	Capital Expenditures, 1986 (in millions)	Standard Option (Ci/Year)	Estimated Capital Costs of Emissions Control (in millions)	Emissions Costs as a Percent of 1986 Capital
Occidental	804.0	10.00	0.00	0.00
		2.00	0.00	0.00
		1.00	0.00	0.00
		0.75	0.00	0.00
		0.60	0.00	0.00
		0.20	2.51	0.31
		0.10	4.53	0.56
		0.06	3.23	0.40
		0.01	8.6	1.07

[1] Based on 1988 Po-210 emissions and risk data.
[2] Converted from French Francs using exchange rate of 0.1571 FF per Dollar.

SOURCE: 1986 Annual reports for Monsanto, FMC, Rhône-Poulenc, and Occidental.

REFERENCES

ADL73 Arthur D. Little, *Economic Analysis of Proposed Effluent Guidelines for the Industrial Phosphate Industry.* Prepared for the Environmental Protection Agency, August, 1973.

An81a: Andrews, V.E., Emissions of Naturally Occurring Radioactivity from Stauffer Elemental Phosphorous Plant, ORP/LV-81-4, EPA, Office of Radiation Programs, Las Vegas, Nevada, August 1981.

An81b: Andrews, V.E., Emissions of Naturally Occurring Radioactivity form Monsanto Elemental Phosphorous Plant, ORP/LV-81-5, EPA, Office of Radiation Programs, Las Vegas, Nevada, August 1981.

CEN78 "Key Chemicals: Phosphorus," *Chemical Engineering News*, April 24, 1978.

CEN79 "Key Chemicals: Phosphorus," *Chemical Engineering News*, April 24, 1979.

CEN81 "Key Chemicals: Phosphorus," *Chemical and Engineering News*, March 23, 1981.

CEN83 "Key Chemicals: Phosphorus," *Chemical and Engineering News*, July 11, 1983.

CEN84 "Key Chemicals: Phosphorus," *Chemical and Engineering News*, July 30, 1984.

CW88j "Soaps and Detergents ... More Punch in the Package," *Chemical Week*, January 20, 1988.

EAB87 U.S. Environmental Protection Agency, *EAB Control Cost Manual*, Third Edition, Research Triangle Park, February, 1987.

EPA77: Environmental Protection Agency, Radiological Surveys of Idaho Phosphate Ore Processing -- The Thermal Plant, ORP/LV-77-3, EPA, Office of Radiation Programs, Las Vegas, Nevada, 1977.

EPA84a: Environmental Protection Agency, *Radionuclides: Background Information Document for Final Rule*, Volume II, EPA 520, Office of Radiation Programs, Washington, D.C., EPA 520/1-84-022-2, October 1984.

EPA84a: Environmental Protection Agency, Radionuclides: Background Information Document for Final Rule, Volume II, EPA 520, Office of Radiation Programs, Washington, D.C., EPA 520/1-84-022-2, October 1984.

EPA84b: Environmental Protection Agency, Regulatory Impact Analysis of Emission Standards for Elemental Phosphorous Plants, EPA, Office of Radiation Programs, Washington, D.C., June 1984.

EPA84c: Environmental Protection Agency, Emissions of Lead-210 and Polonium-210 from Calciners at Elemental Phosphorous Plants: FMC Plant, Pocatello, Idaho, EPA, Office of Radiation Programs, Washington, D.C., June 1984.

EPA84d: Environmental Protection Agency, Emissions of Lead-210 and Polonium-210 from Calciners at Elemental Phosphorous Plants: Stauffer Plant, Silver Bow, Montana, EPA, Office of Radiation Programs, Washington, D.C., August 1984.

EPA84e "Preliminary Analysis of Potential Impacts of $20 Million Compliance Cost at FMC Plant," memorandum from Rod Lorang and Barry Galif, Sobotka, Inc. to Byron Bunger, EPA, February 6, 1984.

EPA89 Vol. 2., *Environmental Impact Statement*

FMC86 FMC Corp., *Annual Report*, 1986.

GARD78 GARD, Inc. *Capital and Operating Costs of Selected Air Pollution Control Systems*, prepared for the U. S. Environmental Protection Agency, Research Triangle Park, N.C., December, 1978.

MCP85 Mannsville Chemical Products Corp., "Phosphorus," *Chemical Products Synopsis*, Cortland, New York, January 1985.

MRI84a: Midwest Research Institute, Analysis of Achievable Po-210 Emission Reductions and Associated Costs for FMC's Pocatello, Idaho, Plant, For the Office of Radiation Programs, EPA, under contract number 68-02-3817, August, 1984.

MRI88 Midwest Research Institute, for Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, *Characterization and Control of Radionuclide Emissions from Elemental Phosphorus Production*, Research Triangle Park, N.C., February 19, 1989.

MY87 William Stowasser, "Phosphate Rock," *Minerals Yearbook*, 1986 pre-print, Volume 1, 1987, p.14.

Ra84a: Radian Corporation, Emission Testing of Calciner Off-gases at FMC Elemental Phosphorous Plant, Pocatello, Idaho, Volumes I and II, Prepared for the Environmental Protection Agency under Contract No. 68-02-3174, Work Assignment No. 131, Radian Corporation, P.O. Box 13000, Research Triangle Park, NC, 1984.

Ra84b: Radian Corporation, Emission Testing of Calciner Off-gases at Monsanto Elemental Phosphorous Plant, Soda Springs, Idaho, Volumes I and II, Prepared for the Environmental Protection Agency under Contract No. 68-02-3174, Work Assignment No. 133, Radian Corporation, P.O. Box 13000, Research Triangle Park, NC, 1984.

Ra84c: Radian Corporation, Emission Testing of Calciner Off-gases at Monsanto Elemental Phosphorous Plant, Soda Springs, Idaho, Volumes I and II, Prepared for the Environmental Protection Agency under Contract No. 68-02-3174, Work Assignment No. 133, Radian Corporation, P.O. Box 13000, Research Triangle Park, NC, 1984.

SAI84: Science Applications, Inc., *Airborne Emission Control Technology for the Elemental Phosphorous Industry*, Final Report to the Environmental Protection Agency, Prepared under Contract No. 88-01-6429, SAI, P.O. Box 2351, La Jolla, CA, January 1984.

SRI80 SRI, *Chemical Economics Handbook*, March 1980.

SRI83 SRI, *Chemical Economics Handbook*, January 1983.

SR186 SRI, *Chemical Economics Handbook*, February 1986.

CHAPTER 9

PHOSPHOGYPSUM

9. PHOSPHOGYPSUM STACKS

9.1 Introduction and Summary

Phosphogypsum stacks are one of twelve industrial sources of radionuclide emissions for which EPA is required to consider controls. In the case of phosphogypsum, the emission of concern is radon. Section 9.2 profiles the phosphate fertilizer industry that generates the phosphogypsum. Section 9.3 describes the controls for radon emissions, their costs, and the reduction of emissions and of the risk of lung cancer that they would provide. Section 9.4 considers the cost per unit of emission reduction attributable to the different combinations of control parameters. Section 9.5 assesses the impact radon control would have on the U.S. economy. Section 9.6 provides an analysis of the regulatory flexibility of the controls.

The overall conclusions regarding controls on phosphogypsum stacks to reduce the risk of cancer due to radon emissions are: 1) the controls that will reduce risk the most can be provided to the fourteen phosphogypsum stacks for which data was available for about $251 million (discounted at 5 percent), 2) the most stringent controls would reduce risk to the 80 km populations by 3E-1, and 3) using the most expensive version of the controls will add an average of $14 per ton to the cost of producing phosphoric acid and reduce the export of phosphoric acid from the U.S. by approximately 11 percent over the next thirty years.

9.2 Industry Profile

Phosphogypsum is a waste product resulting from the production of wet process phosphoric acid used in the manufacture of fertilizer and animal feed. Phosphate-bearing ore is mined and then processed to remove clay and other impurities. The purified ore is called phosphate rock. The phosphate rock is then reacted with sulfuric acid, producing phosphoric acid and the waste product phosphogypsum (calcium sulfate). Of all the marketable phosphate rock mined in the United States annually, about 90 percent is used in the production of wet-process phosphoric acid (WPPA). Thermal phosphoric acid is produced with the remaining 10 percent.

Phosphorus, along with potassium and nitrogen, is one of the primary nutrients which plants require. All living things contain phosphorus, a basic element essential to life. It ensures the transfer and storage of energy and plays a role in the metabolic process. Phosphorus is not naturally very abundant in soils, as it is constantly removed by crops and natural losses. Phosphate applications help produce high crop yields and improve the biological quality of the crop. The phosphate mineral itself is very insoluble and is therefore a poor source of phosphorus for plants. Thus, the phosphate rock is treated with excess sulfuric acid to produce merchant-grade WPPA, containing 52 to 54 percent P_2O_5 (phosphorus pentoxide, the unit commonly used to express phosphorus content) [St85].

The U.S. phosphate industry was the world leader in downstream[1] fertilizer products after initiating major expansions in the 1970s. However, in the 80s many foreign rock producers have been investing in their own downstream product facilities with the result that in the near future all major rock exporters and producers will have their own phosphoric acid and fertilizer production capability.

The 1980s have been a difficult period for the U.S. phosphate industry. Besides the rapid growth of foreign production capacity, the domestic industry has suffered from rapid changes in demand for phosphate fertilizer. As a result, sales of phosphate products have declined, losses have been incurred throughout the industry and several companies have filed for bankruptcy, closed their phosphate operations, or sold their phosphate operations. Nevertheless, the U.S. industry continues to dominate the domestic market and total production and exports have shown promise of improving, though the value of sales has not improved. Phosphate fertilizer sales were $3.9 billion in 1987, down from $4.5 billion in 1984. Sales in the second quarter of 1988, however, increased 12 percent from levels in 1987 [DOC88a, TFI88b].

However, the outlook for the domestic phosphate industry is complicated by the depletion of major phosphate rock deposits in central Florida. The Bone Valley of Florida, which contains many of the lowest cost deposits in the world, is being rapidly depleted. Many nearby deposits are available or could be developed, but at a higher cost and lower grade. Over the next 20 years, there will be a high level of mine replacement. Average production costs in Florida will be rising faster than those in much of the rest of the world, where current mines can continue production for many years [BSC85a].

Morocco and Florida represent the two sides of the phosphate industry. The Moroccan state-owned company has aggressively expanded phosphate rock, acid and fertilizer capacity even when the international market had excess capacity. And while Florida production costs are now the lowest, Morocco has a variety of cost advantages, including closer proximity to key export markets [BSC85a]. The future of the U.S. phosphate industry depends on its ability to remain competitive against countries like Morocco.

---

[1] Downstream fertilizer products include: diammonium phosphate, and triple super phosphate, as well as some items manufactured in smaller quantities.

9.2.1 Characteristics of Phosphoric Acid Production

9.2.1.1 Determinants of Phosphoric Acid Supply

Nearly 9.5 million metric tons of phosphoric acid were produced in the U.S. in 1987. Total U.S. phosphoric acid production grew steadily during the late 1960s and the 1970s and reached a peak of nearly 10.3 million tons in 1980 [DOC81].[2] During the 1970s, significant new production capacity was added in response to sharply higher prices for phosphate fertilizer products. In the early 1980s, when this capacity became available, however, demand for phosphoric acid declined. As shown in Table 9-1, production levels declined to 7.5 million tons in 1982, a drop of 25 percent from 1980. In recent years, production levels have improved but have remained erratic, reaching a new high of 10.3 million tons in 1984. Production of phosphoric acid in the first half of 1988 is 13 percent above the levels in the first half of 1987.

Also evident in Table 9-1 is the close link between the production levels of phosphoric acid, WPPA and phosphate fertilizer. The second column of Table 9-1 shows production levels of wet process phosphoric acid (WPPA). Almost all phosphoric acid is produced as WPPA and the production levels of WPAA parallel the levels of total phosphoric acid. Similarly, most WPPA is used in the production of phosphate fertilizer, shown in the third column of Table 9-1. Production levels for phosphate fertilizers for the first half of 1988 are 6 percent above the levels in the first half of 1987 and producer's stocks of phosphate fertilizers have remained essentially unchanged between these periods [DOC88b].

In addition to changes in total production levels for phosphate products, there have been trends in the types of phosphate fertilizers that are produced. As shown in Part 2 of Table 9-1, diammonium phosphate (DAP) has come to dominate the phosphate fertilizer market. DAP's share of total production has grown from 39 percent in 1974 to 69 percent in 1986. The production levels of concentrated superphosphates have dropped from 24 percent of total production in 1974 to 16 percent in 1986. Production levels of normal and enriched superphosphates and monoammonium phosphates have also declined [DOC80].

---

[2] 1 short ton = 2,000 pounds
1 metric ton = 1,000 kilograms = 2,205 pounds
"Tons" in this document refers to metric tons unless otherwise specified.

Table 9-1: Production of Phosphoric Acid, Wet Process Phosphoric Acid and Phosphate Fertilizer.
(Part 1 of 2)

Metric Tons

YEAR	TOTAL PHOSPHORIC ACID		WET PROCESS PHOSPHORIC ACID	TOTAL PHOSPHATE FERTILIZER	
	PRODUCTION	PERCENT OF 1970 BASE	PRODUCTION	PRODUCTION	PERCENT OF 1970 BASE
1987	9,691,381	184	9,134,164	6,444,234	161
1986	8,686,919	168	8,146,432	5,540,068	133
1985	9,620,478	187	9,076,701	6,941,434	167
1984	10,334,304	200	9,718,541	7,284,941	175
1983	8,858,334	172	8,261,672	6,400,026	154
1982	7,485,244	145	6,933,111	5,084,640	122
1981	9,031,701	175	8,417,517	6,266,839	150
1980	9,921,673	192	N/A	7,563,636	181
1979	9,357,519	181	N/A	6,949,424	167
1978	8,675,364	168	N/A	6,508,518	156
1977	8,124,453	158	N/A	6,075,729	146
1976	6,845,673	133	N/A	5,282,334	127
1975	6,957,597	135	N/A	5,054,855	121
1974	6,465,096	125	N/A	4,867,854	117
1973	6,211,045	120	N/A	5,059,401	121
1972	5,923,345	115	N/A	4,972,537	119
1971	5,414,790	105	N/A	4,527,291	109
1970	5,157,202	100	N/A	4,168,663	100
1969	4,928,638	96	N/A	3,893,207	93
1968	4,779,890	93	N/A	3,763,506	90
1967	4,598,490	89	N/A	4,258,365	102
1966	4,167,665	81	N/A	4,035,878	97

Source: Bureau of the Census, Current Industrial Reports
Summary reports for 1987, 1986, 1985, January 1982, 1980, 1979, 1978, 1976, 1974, 1973.

Table 9-1: Production of Phosphoric Acid, Wet Process Phosphoric Acid and Phosphate Fertilizer.
(Part 2 of 2)

Metric Tons

YEAR	BREAKDOWN OF TOTAL PHOSPHATE FERTILIZER PRODCUTION NORMAL & ENRICHED SUPERPHOSPHATES	CONCENTRATED SUPERPHOSPHATES	DIAMMONIUM PHOSPHATE	OTHER PHOSPHATE FERTILIZERS
1987	58,088	867,101	4,550,845	968,200
1986	59,129	881,512	3,829,047	770,380
1985	91,441	1,079,364	4,843,020	927,610
1984	115,023	1,019,321	5,264,103	886,494
1983	110,776	1,129,675	4,337,248	822,327
1982	125,746	966,163	3,338,334	654,398
1981	215,369	1,352,681	3,696,905	1,001,885
1980	412,986	1,535,601	4,509,868	1,105,181
1979	320,012	1,670,263	3,861,275	1,097,874
1978	264,057	1,650,616	3,569,683	1,024,163
1977	308,360	1,624,232	3,133,542	1,009,595
1976	346,981	1,446,577	2,608,263	880,514
1975	439,040	1,521,848	2,407,662	686,305
1974	632,790	1,559,068	1,904,436	771,560
1973	561,873	1,535,258		314,526
1972	613,858	1,504,441		517,171
1971	567,782	1,371,838		415,225
1970	607,690	1,336,737		327,246
1969	731,677	1,228,169		260,944
1968	828,635	1,259,642		194,461
1967	1,073,707	1,343,086		257,225
1966	1,031,985	1,538,726		216,682

Source: Bureau of the Census, Current Industrial Reports
Summary reports for 1987, 1986, 1985, January 1982, 1980, 1979, 1978, 1976, 1974, 1973.

Price Trends

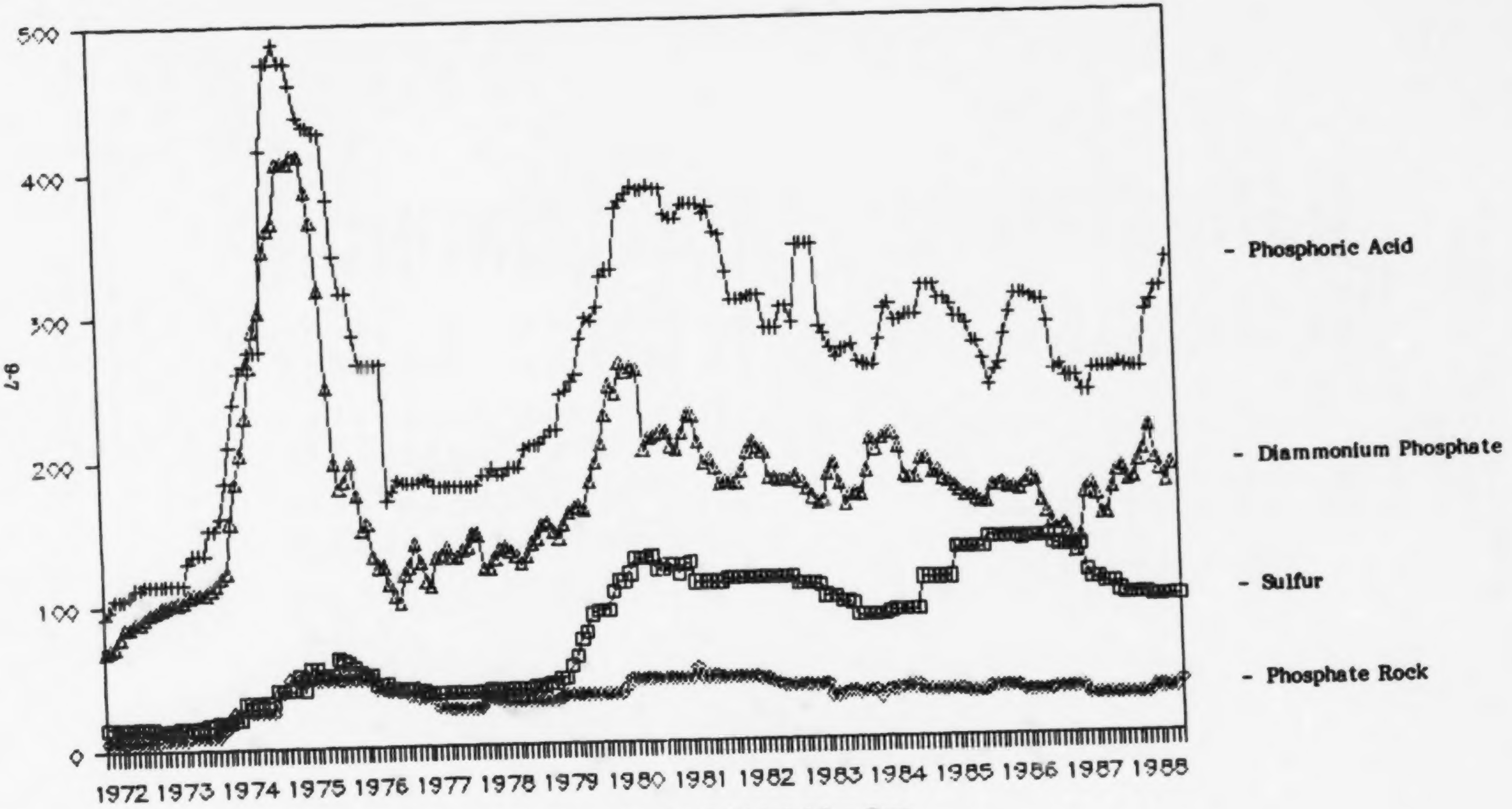
Spot prices of WPPA have varied considerably in the 1970s and 1980s. These changes have an enormous influence on the cost of phosphate fertilizers. WPPA represents 70 percent of the production costs of diammonium phosphate and 69 percent of the cost of granular triple super phosphate (TSP) [TFI87c]. TSP also requires some phosphate rock in its production, contributing another 9 percent of its production cost. Table 9-2 shows the prices for phosphoric acid and fertilizer in absolute and constant dollars. Table 9-2 also gives prices for sulfur and phosphate rock, the two most important inputs to WPPA. These inputs will be discussed in detail later in this chapter. Figure 9-1 graphs the changes in prices of the commodities listed in Table 9-2. The prices considered in these exhibits are for the export market for product loaded and leaving from terminals in the Gulf of Mexico. Prices in this market are more volatile than prices determined by long term contracts. The price for WPPA shipped under long-term contracts, however, are not often published.

In the early 1970s, fertilizer prices were restrained in the U.S. by the national wage and price controls. After wage and price controls ended, prices increased rapidly, reaching a high in the middle of 1974. The price for phosphoric acid in 1974 was $712 per ton (1982 dollars). It dropped by 62 percent to $271 (1982 dollars) by 1977 and rebounded to $439 (1982 dollars) per ton in 1980. Prices have declined since 1980, to $257 per ton (1982 dollars) in the spot market in April 1988. The April 1988 price, in current dollars, was $307.50 [BSC88b].

Plants and Operating Capacity

There are 20 operating WPPA plants in the U.S. [TVA88]. According to the Tennessee Valley Authority, six of their plants were indefinitely closed in the mid-1980s. Two other plants, owned by the bankrupt Beker Industries Company, are closed and for sale. The eight plant shutdowns have resulted in a U.S. WPPA capacity reduction of 1.4 million tons per year. The 20 plants in operation give the U.S. a capacity of 11.5 million tons of WPPA. Since 1984, the 20 operating plants have increased overall capacity by 735,000 tons, although one of these plants reduced capacity by 100,000 tons [TVA88]. There are 11 WPPA plants operating in Florida, comprising 67 percent of the capacity of U.S. plants still in operation. Louisiana has 4 operating WPPA plants and the remainder are distributed among North Carolina, Mississippi, Texas, Idaho and Wyoming.

Figure 9-1: Price of P205 and Related Products



Source: British Sulphur Corp.

Table 9-2: Price of Phosphoric Acid, Sulfur Phosphate Rock and Diammonium Phosphate.

(Average of Monthly Prices)

	PHOSPHORIC ACID	SULFUR	PHOSPHATE ROCK	DIAMMONIUM PHOSPHATE
1972	$111.46	$15.69	$7.77	$89.96
1973	$155.42	$17.97	$13.55	$120.33
1974	$384.38	$37.64	$35.43	$332.29
1975	$359.38	$54.57	$48.00	$247.29
1976	$196.59	$40.18	$37.00	$119.36
1977	$182.29	$37.30	$28.04	$133.25
1978	$202.29	$40.45	$31.04	$139.29
1979	$292.33	$83.36	$34.42	$197.04
1980	$376.46	$122.77	$44.50	$223.25
1981	$341.88	$111.25	$45.17	$193.29
1982	$310.54	$110.31	$39.17	$180.67
1983	$268.46	$90.33	$31.96	$182.13
1984	$299.42	$98.63	$33.17	$189.08
1985	$274.25	$133.75	$32.92	$168.96
1986	$279.38	$133.63	$32.00	$154.21
1987	$250.46	$101.75	$27.25	$173.46
1988	$306.50	$94.00	$32.54	$188.60

CONSTANT DOLLARS
1982 DOLLARS

	PHOSPHORIC ACID	SULFUR	PHOSPHATE ROCK	DIAMMONIUM PHOSPHATE
1972	$239.70	$33.73	$16.72	$193.46
1973	$313.97	$36.31	$27.38	$243.10
1974	$711.81	$69.70	$65.61	$615.35
1975	$606.03	$92.02	$80.94	$417.02
1976	$320.59	$64.14	$59.17	$189.91
1977	$270.86	$55.42	$41.67	$197.99
1978	$280.18	$56.03	$42.99	$192.92
1979	$371.93	$106.05	$43.79	$250.69
1980	$439.27	$143.26	$51.93	$260.50
1981	$363.70	$118.35	$48.05	$205.63
1982	$310.54	$110.31	$39.17	$180.67
1983	$258.38	$86.94	$30.76	$175.29
1984	$277.49	$91.40	$30.74	$175.24
1985	$245.96	$119.96	$29.52	$151.53
1986	$244.85	$117.11	$28.05	$135.15
1987	$213.16	$86.60	$23.19	$147.62
1988	$251.23	$77.05	$26.67	$154.59

All data are in dollars per metric ton. Phosphoric acid and diammonium phosphate prices are FOB US Gulf; phosphate rock is FOB Florida, and sulfur is FOB Vancouver. GNP Deflator used to compute constant-dollar series.
Source: Data purchased from British Sulphur Corp., June 5, 1988.

Production Costs

Estimates of the production costs of WPPA are available from a variety of sources. Table 9-3 shows estimates from The Fertilizer Institute (TFI). The data are from an industry survey of U.S. producers of 1986 costs. According to the TFI estimates, sulfuric acid represents 49 percent of the cost of producing phosphoric acid. Over 96 percent of the cost of sulfuric acid is accounted for in purchasing the sulfur itself. Phosphate rock represents another 31 percent of the production cost of phosphoric acid. Energy costs represent 6 percent of production costs. Per ton of phosphoric acid requires 2.74 tons of sulfuric acid and 3.55 tons of phosphate rock. Plants with an annual capacity over 400,000 tons enjoy a considerable cost advantage over smaller plants. According to the TFI survey, large plants had an average production rate of $229 per ton, compared to $289 for plants with a capacity under 400,000 tons. The average cost in 1986 was $239.35 per ton [TFI87d].

Traditionally, phosphoric acid production occurred almost entirely in tandem with fertilizer production. However, improved transportation options and heightened international competition has created a distinct market for the production and sale of phosphoric acid.

Transportation Costs

The markets a nation's phosphate industry serves depend in large measure on transportation costs. In March 1988, the cost to ship a ton of phosphoric acid from the Gulf of Mexico to India averaged $48, a little over 15 percent of the current U.S. price [BSC88a]. North African producers have a transportation advantage over U.S. producers for many markets. According to estimates by Zellars-Williams for the cost of shipping one type of phosphate, DAP fertilizer, Morocco and Tunisia have a $5 per ton advantage shipping to northern Europe and India. Freight costs to China are essentially the same for both regions [Ze86].

Few U.S. phosphoric acid producers have their own shipping fleets. The notable exception is Occidental Petroleum Co., which has a dedicated fleet of three vessels supplying contract deliveries of phosphoric acid to the Soviet Union. Office Cherifien Des Phosphates (OCP) of Morocco and ICM of Tunisia both ship phosphoric acid, using captive tonnage. Brazil and India, important phosphoric acid consumers, have both invested in dedicated fleets of phosphoric acid tankers, but the bulk of their import requirement continues to be met by outside carriers.

With the exception of phosphoric acid, phosphate products do not require specialized handling facilities and these products can be readily shipped in conventional bulk carriers. The market for

Table 9-3: Phosphate Fertilizer Production Costs

	Cost per metric ton	Percent of total cost
Wet Process Phosphoric Acid		
Sulfuric Acid	130.07	49.3%
Phosphate Rock	81.24	30.8%
Electricity	6.44	2.4%
Steam	10.22	3.9%
Operating Labor	4.70	1.8%
Other	31.21	11.8%
Total	263.88	100%
Diammonium Phosphate		
Phosphoric Acid	126.90	70.5%
Anhydrous Ammonia	30.02	16.7%
Electricity	1.68	0.90%
Steam	3.53	2.0%
Operating Labor	1.91	1.1%
Other	16.42	8.8%
Total	180.45	100%
Granular Triple Super Phosphate		
Phosphoric Acid	88.71	69.5%
Phosphate Rock	10.98	8.6%
Electricity	2.95	2.3%
Natural Gas	2.27	1.8%
Operating Labor	2.58	2.0%
Other	20.19	15.8%
Total	127.68	100%

Source: Phosphate Fertilizer Production Cost Survey, Year Ended December 31,1986. Compiled by National Fertilizer Development Center for The Fertilizer Institute, May 1,1987. pp.2-5.

such vessels has been characterized by chronic oversupply throughout the 1980s, and freight rates have steadily declined. It is not clear how freight rates will vary over the next several decades. British Sulphur Corp. has only made forecasts for the short term and Zellars-Williams's forecasts assume rates will remain essentially the same between 1985 and 2005.

Fertilizer producers historically have located phosphoric acid production near either phosphate rock or sulfur supplies. Economical domestic supplies of phosphate rock and sulfur have been an essential factor in allowing the U.S. to obtain its dominant position in the international market. Thus, the outlook for the domestic phosphoric acid industry depends in large measure on the availability of economical supplies of phosphate rock and sulfur.

Phosphate Rock

The production of WPPA requires a phosphate rock product whose specifications are most easily achieved from deposits in the Bone Valley Formation of Central Florida. Most North Carolina phosphate rock deposits are of a lower grade primarily because of a high level of organic matter. Western rock is of even lower grade [St86a]. Thus, most of the rock acid used to produce WPPA comes from Florida. In 1986, Florida produced about 80 percent of the phosphate rock in the United States and over 95 percent of that went for the production of WPPA [DOC87].

In 1986, U.S. mines produced 38.7 million tons of phosphate rock, down from levels in 1984 and 1985 that were around 50 million tons. Each year approximately 20 percent of U.S. phosphate rock production is exported. A small amount of rock is imported, often to obtain high-grade rock for making especially pure phosphoric acid. Trends in world production levels of phosphate rock have paralleled trends in U.S. production levels.

Most phosphoric acid plants operating in the United States enjoy a significant competitive advantage over potential new firms because their parent companies own rock reserves, which are mined relatively cheaply. Plants that do not have a rock mine on site are usually supplied by a mine that can be linked by barge. U.S. mines had average production costs of $15.60 per ton in 1986, according to TFI [TFI87d]. In contrast, the export price in 1986 from Florida for equivalent rock was $25.02 per ton [St86a]. Because 3.6 tons of rock are used in making one ton of P_2O_5, this difference in cost translates into approximately a $33 per ton cost difference for domestic phosphoric acid production compared to the cost of purchasing rock for export sale, 25 percent of total average production costs. The continued availability of low cost phosphate rock is a central factor in the future of the phosphate industry.

The U.S. rock mining capacity far exceeds that of any other nation. According to the Bureau of Mines, the U.S. capacity of nearly 62 million tons is twice as large as the next country, the U.S.S.R., which has 31 million tons capacity. Africa has a 48 million ton capacity, with over half of that in Morocco. Table 9-4 lists rock capacity by each major country, according to both the Bureau of Mines and Zellars-Williams.

Phosphate Rock Reserves -- Estimating the size of phosphate reserves requires many assumptions. Estimates by the U.S. Bureau of Mines and the U.S. Geological Survey classify reserves according to the extent to which assumptions needed to be made. The reserve estimates are ranked according to the level of confidence: demonstrated, inferred, hypothetical, and speculative levels. Demonstrated reserves are those that can be profitably extracted using current technology. The level of demonstrated reserves changes with new technological development and significant changes in market conditions. At the demonstrated resource level, there are approximately 35 billion tons of recoverable rock worldwide in 28 market economies, located in approximately 200 deposits. Fifty-six percent of this is in Morocco and 19 percent is in the United States. There is a further 1.5 billion tons of recoverable rock located in the U.S.S.R. and China. An estimated 95 billion tons of recoverable phosphate rock exists at the demonstrated, inferred, hypothetical, and speculative levels [BOM84].

Worldwide availability of demonstrated recoverable rock reserves is shown in Table 9-5. Within the United States as of 1983, 5.4 billion tons of phosphate rock were potentially recoverable at the demonstrated reserve level as defined above. Approximately 3.7 billion tons of this was located in Florida and North Carolina. As of 1983, 1.4 billion tons were available at costs ranging up to $30 per ton. Three-fourths of the demonstrated reserves in Florida and North Carolina is available at a cost of less than $45 per ton [St85].

Inferred deposits are estimates that assume a continuity from indicated resources which are based on geological evidence. Hypothetical resources are another step away from direct geological evidence than are inferred resources. Hypothetical reserves "may be reasonably expected to exist ... under analogous geologic conditions [BOMb]." At the inferred level, 7 billion tons of rock are available in the U.S., 80 percent of which is in the Southeast. Twenty-four billion tons are available at the hypothetical level, with 60 percent in the Southeast. A further 2 billion tons have been identified, but are high in magnesium content so are not currently profitable to process. New discoveries are likely, particularly offshore along the eastern seaboard, and new technologies could easily increase the amount of profitably-recoverable phosphate rock [BOMb].

Table 9-4: Phosphate Rock Statistics on World Supply
Rock Mining Capacity.

(MILLION TONS PER YEAR, DRY BASIS)

LOCATION	WORLD PHOSPHATE ROCK CAPACITY,USBM \1				Zellars-Williams Rock Production Forecast\2				
	1985	1990	1995	2000	1985	1990	1995	2000	2005
NORTH AMERICA	61.7	67.1	62.2	45.9	48.1	58.0	58.6	56.2	52.3
United States	61.7	67.1	62.2	45.9					
CENTRAL AMERICA	1.0	2.5	2.5	3.5	0.6	1.8	2.3	2.3	2.3
Mexico	1.0	2.5	2.5	3.5					
SOUTH AMERICA	4.5	7.0	9.0	10.0	3.8	5.0	5.0	5.0	5.0
Brazil	4.5	7.0	8.0	8.0					
Peru	-	-	1.0	2.0					
WESTERN EUROPE	0.5	0.6	0.6	1.1	0.8	0.8	0.8	0.8	0.8
Finland	0.5	0.5	0.5	1.0					
Turkey	-	0.1	0.1	0.1					
EASTERN EUROPE	31.0	36.0	45.0	50.0	31.0	35.1	38.9	42.6	45.1
USSR	31.0	36.0	45.0	50.0					
AFRICA	48.1	57.1	62.1	68.1					
Algeria	2.2	2.2	2.2	2.2					
Egypt	1.2	1.2	1.2	1.2					
Morocco	28.0	35.0	38.0	44.0	21.3	28.4	34.0	44.0	54.0
Senegal	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9
South Africa, Rep. of	4.7	4.7	5.7	5.7	3.0	3.4	3.4	3.4	3.4
Togo	3.0	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
Tunisia	7.0	9.0	10.0	10.0	4.6	7.2	10.2	11.0	13.4
ASIA	27.1	36.6	49.1	60.6					
China	13.0	20.0	30.0	40.0	17.0	17.8	21.0	24.0	25.0
Israel	3.5	5.0	6.5	6.5	3.0	3.5	3.5	3.5	3.5
Iraq	1.7	1.7	1.7	1.7					
Jordan	6.5	7.5	8.5	10.0	5.0	6.0	10.0	12.0	12.0
Syria	2.4	2.4	2.4	2.4					
OCEANIA									
Australia	1.0	1.0	1.0	1.0					
Christmas Island \3	1.8	1.8	3.0	3.0					
Nauru	2.0	2.0	2.0	-					
WORLD TOTAL \4	290.9	351.5	404.8	436.5	142.6	171.4	192.1	209.2	221.2

\1 Source: W.F. Stowasser, Phosphate Rock: World Resources, Supply and Demand, 1986.
Figures for all years are U.S. Bureau of Mines estimates based on the size of the reserve base. Unfavorable
economics may alter the forecasted rock capacities in future years.
\2 Source: Phosphate Rock 1985/86, by Zellars-Williams. Blanks mean data is not available. This data are not
directly comparable to the Stowasser estimate. The Stowasser estimate of capacity in each year does not
imply that the capacity will be used fully. Zellars-William's production forecast may allow for some unused
capacity, especially in 1985. Nevertheless, a comparison of the data reveals different outlooks.
\3 Christmas Island closed at the end of 1987.
\4 Cannot accurately compare world totals between the two sources as both do not contain all the same data.

Table 9-5: Phosphate Rock Statistics in World Supply Demonstrated Rock Reserves.

LOCATION	NUMBER OF DEPOSITS	RESERVES (Million Metric Tons\1)	RESERVE BASE (Millions Metric Tons\2)
United States	108	1,400	5,400
Florida		520	2,400
North Carolina		400	1,300
Idaho		50	220
Utah		220	730
Wyoming		-	690
Other		210	60
Canada	1	-	40
Mexico	2	-	120
Brazil	9	40	350
Columbia	1	-	100
Peru	1	-	140
Finland	2	-	110
Turkey	1	-	30
USSR	11	1,300	1,300
Algeria	1	-	250
Egypt	5	-	790
Morocco & Western Sahara	12	7,750	20,850
Morocco	11	6,900	20,000
Western Sahara	1	850	850
Senegal	2	130	130
South Africa, Republic of	1	2,600	2,600
Togo	1	50	50
Tunisia	7	60	120
China	6	210	210
Israel	3	20	90
Jordan	3	120	510
Syria	2	-	180
Australia	4	-	500
Other	9	320	130
WORLD TOTAL	192	14,000	34,000

\1 Cost less than $35 per metric ton. Cost includes capital, operating expenses, taxes, royalties, miscellaneous costs, and a 15% rate of return on investment. Costs and resources as of January 1983, F.O.B. Mine.

\2 Cost less than $100 per metric ton; costs as defined in footnote 1.

SOURCE: W.F. Stowasser, USBM Mineral Facts and Problems 1985

There are many unknowns in estimating resource reserves. For example, there is speculation about a new deposit in North Carolina. Details have not been finalized and tests will take two years to complete after they have begun. Should this deposit be realized, an estimated 70 to 90 million metric tons of new phosphate rock reserves could be added to North Carolina reserves and the costs could be as low as $7 to $10 per ton [BSC87b].Prices -- The price of phosphate rock has followed a similar set of swings as has the price of WPPA. Table 9-2 lists phosphate rock export prices between 1972 and 1988. Prices have fallen from around $45 per ton in 1980 and 1981 to between $27 and $31 per ton in 1987 and 1988 [BSC88b].

Production Forecasts -- Rock production forecasts require a number of assumptions concerning the price and demand for phosphate rock, as well as operating costs in future years for known but undeveloped deposits. William Stowasser at the U.S. Bureau of Mines and Zellars-Williams have made the most careful production forecasts. While both sources anticipate similar trends, Stowasser is considerably more pessimistic concerning the prospects for U.S. rock production after the year 2000.

Stowasser forecasts that U.S. production of phosphate rock will be 46.4 million tons per year by the year 2000 [St85] and will decline significantly after that to about 28 million metric tons in 2010 [BOM88d]. Stowasser reexamined this forecast in June of 1988 after a survey of company's production plans and did not significantly modify his forecast [BOM88c]. The production level in the year 2000 is within the range of production achieved in the mid-1980s. Rock production from Florida is expected to decline at a rapid rate after 2010 as reserves in currently operating mines in the Bone Valley are exhausted. Production from North Carolina will increase through 2000 and be about 10 million tons in 2010. Other U.S. production will remain about the same. These forecasts assume an economically competitive technology will not be developed that would permit utilizing undeveloped central Florida phosphate resources [BOM88c]. Thus, in Stowasser's forecast, sufficient domestic supply will not be available after the year 2000 to satisfy demand at production levels being met in the 1980s. Such a scenario would force major increases in the price of phosphate rock.

The Zellars-Williams supply estimate is more optimistic and forecasts 56.2 million tons per year in the year 2000 and 52.3 in 2005. The accuracy of both of these forecasts depends on trends in the phosphate markets, such as the demand and price of phosphate rock. For example, the current oversupply situation in the world could cause the decline to occur several years later as rock sales may be below production capacity. However, each forecast expects that there will be a decline in rock capacity in the U.S. in the next 20 to 25 years.

The forecasts of production described above do not indicate the future price of phosphate rock. Industry experts have consistently avoided forecasting price levels. However, some indication of future prices for phosphate rock can be found from examining forecasts of the cost of producing phosphate rock. A study by Fantel, Stowasser and others at the Bureau of Mines examined 201 mines. Fantel, *et. al.*, made separate estimates for mines operating in 1981 and for undeveloped mines. The study estimated that mines operating in 1981 could produce, in 1995, 10.8 million tons a year of rock for between $18 and $30 and another 1.4 million tons for between $30 and $40. This estimate assumed the mines operated at full capacity since 1981. The study also forecasted that undeveloped mines could produce 10.3 million tons for between $27 and $35, another 21.8 million tons for between $35 and $45 per ton [Fa83]. The estimate for undeveloped reserves is based on production levels that would be attained 10 years after development is initiated.

To estimate production costs in the year 2000, it is necessary to make several assumptions. The study described above noted that the forecast for currently operating mines should be revised in the future if the mines do not operate at full capacity. Because they have frequently operated below capacity, it is reasonable to assume that the developed reserves continue at 1981 production levels until the year 2000. It is necessary to assume that the new reserves begin, on average, to be developed in 1990 and that the cost of production estimates in this study are spread evenly over the cost range given. With these assumptions, it is apparent that the marginal cost of production at 1980 production levels, such as 40 million tons, would be $43 per ton in 1981 dollars. The average cost of production would be $33 per ton. Assuming that the price of phosphate rock equals the marginal cost of production and adjusting for inflation, this forecast suggests that the U.S. open market price of phosphate rock will almost double from current prices by the year 2000.

Not all domestic phosphoric acid producers will be forced to pay more for phosphate rock. This is because many phosphoric acid producers have captive rock mining capacity and the average cost of production is approximately ten dollars below the marginal cost. Consequently, the production costs for all phosphoric acid producers will not increase to the full extent of the potential price increase. However, if production cost is measured using the opportunity cost to the producer, the production cost for all producers would increase.

Maintaining current rock production will require major capital investment by the phosphate industry during the next several decades. Fantel, *et. al*, at the Bureau of Mines, estimate that the initial capital cost to develop new potential surface phosphate mines is between $75.20 and $88.40 per ton. They project that U.S. mining capacity will decline by 39 million tons between 1981 and 1995, assuming the plants operate at full capacity. Since many plants have been operating below market capacity, it is reasonable to extend the operating levels to the year 2000. Replacing this capacity will require industry investment of between $2.9 and $3.4 billion before the year 2000 [Fa85]. However, the higher costs of production diminish the incentives for this level of investment.

Though phosphate rock mining capacity in the U.S. is expected to decline, both Zellars-Williams and the Bureau of Mines expect rock mining capacity to grow rapidly throughout the rest of the world. The Bureau of Mines projects that Morocco will increase its capacity to 44 million tons per year by the year 2000 and that the People's Republic of China will increase its capacity from 13 to 40 million tons per year. Many other countries will also expand so that world capacity will grow from 291 million tons in 1985 to 436 million tons in the year 2000 [St86b]. Country by country projections by both the Bureau of Mines and Zellars-Williams are contained in Table 9-4.

Sulfur

Approximately 60 percent of sulfur used in the U.S. is consumed in the production of phosphoric acid [Mo85]. Sulfur is produced in the U.S. either as a by-product from the processing of other materials (known as "recovered sulfur") or from mining. Most U.S. sulfur is recovered at natural gas wells, during the refining of petroleum and during the processing of some minerals, such as copper. Sulfur is also mined at a small number of sites. In the case of recovered sulfur, the supply is insensitive to the price and demand for sulfur so long as its price is low enough that it does not dominate the decision to produce natural gas or petroleum. The supply of recovered sulfur is extremely sensitive to changes in the use of natural gas and petroleum products. The burden for adjusting to shifts in demand rests on sulfur mines.

Most sulfur is used in production processes, such as making phosphoric acid, after being converted into sulfuric acid. According to a survey sponsored by The Fertilizer Institute, the cost of obtaining sulfur represents 96 percent of the cost of producing sulfuric acid. Each ton of sulfur can produce 3 tons of sulfuric acid [TFI87c]. Because of this increase in weight and volume, sulfur is usually transported to the plant where it will be used and then converted into sulfuric acid. However, a number of processes described in the following text produce sulfuric acid instead of elemental sulfur. In addition, some sulfuric acid users are too small to engage in converting sulfur into sulfuric acid, and, consequently, purchase acid directly.

Sulfur resources are abundant throughout the world. Billions of tons of sulfur could be recovered from coal and oil shale but cost-competitive processes are not available. However, some sulfur is now extracted as a by product from these sources in order to meet environmental standards. Following is a review of the current sources of sulfur and forecasts of future supply of sulfur.

Current Production Recovered Sulfur -- Recovered sulfur supplied 52 percent of U.S. sulfur production in 1986. Recovered sulfur provides a similar proportion, 55 percent, of world production. The sulfur is recovered where petroleum is processed and where sour natural gas is taken from the ground. "Sweet" and "sour" refer to oil and gas sources with relatively small and large quantities of sulfur, respectively. Texas, Mississippi and Louisiana produced 47 percent of U.S. recovered sulfur in 1986 [Mo85]. The quantity of sulfur in oil and gas varies greatly.

In recent years, there has been a trend towards the production of a higher proportion of sour energy sources. This trend reflects the depletion of easier-to-refine sweet oil and gas. Sour natural gas is poisonous and highly corrosive and, consequently, more expensive to refine.

In the international market, Canada is the dominant exporter. Canada has been producing recovered sulfur for decades. Not until the mid-1960s, with the growth of the phosphate fertilizer industry, was there an important international market for sulfur. Canada, consequently, has had substantial inventories. Canada had an inventory of 20.4 million tons in 1979, which had shrunk to 6.7 million tons by 1987. Canada produced 5.9 million tons in 1987 [Ph88]. Production in the U.S. and U.S.S.R. exceeds Canadian production but in both countries the sulfur is largely used domestically.

Current Production of Mined Sulfur -- Two technologies are most important in the mining of sulfur: Frasch mining and pyrite mining. The Frasch technology extracts the sulfur by pumping large quantities of superheated water into underground deposits. The melted sulfur settles at the bottom of the well and is pumped out. While Frasch is the only technology used in the U.S., several other extraction methods are used elsewhere. There are four domestic sulfur mining producers, with four sulfur plants operating in 1986 in Texas and Louisiana and several plants idle. Three of the four producers, Freeport Minerals Co., Farmland Industries and Texasgulf Chemicals Co. are phosphoric acid producers. The fourth producer, Penzoil Sulfur Co., does not produce phosphoric acid. Farmland Industries sulfur mines were last reported closed. Throughout the world, Frasch mining contributes a little over 20 percent of sulfur production [Mo87].

Sulfur is mined outside the U.S. from pyrite deposits. The sulfur in these deposits is usually recovered as sulfuric acid (H_2SO_4) instead of as elemental sulfur. While phosphoric acid plants use sulfuric acid, the cheapest form to transport is elemental sulfur. Thus, while sulfur from pyrite deposits represents 19 percent of world production, it is not an attractive supply source for U.S.

demand. The economics of pyrite deposits are often improved by the presence of valuable minerals within the deposit. Such minerals, including copper, lead, gold, zinc, and silver, make deposits less rich in sulfur still profitable to exploit [Bu86].

In general, the location of sulfur production has benefitted U.S. producers of phosphoric acid in comparison with foreign competitors. Because the U.S. is an important oil and gas producer and consumer and because the U.S. has developed Frasch mines, domestic phosphoric acid producers have had convenient, ample sources of sulfur supply. Many foreign phosphoric acid producers, however, have little or no domestic sulfur production. Morocco, for example, imports most of its sulfur from Canada. Phosphoric acid production cost estimates by Zellars-Williams gave U.S. producers a cost per ton for sulfuric acid approximately $5 lower than Morocco producers. This difference amounts to a $13.70 cost advantage per ton of phosphoric acid.

Prices -- Because significant inventories of sulfur existed in the late 1960s, the increased demand for phosphoric acid and the corresponding increase in demand for sulfur did not lead to wide swings in price of sulfur as in the price of phosphate rock and phosphoric acid. Sulfur prices increased at almost half the rate of phosphate rock prices in the early 1970s. Nevertheless, the price increase was substantial. Between 1972 and the middle of 1980, sulfur prices had increased from $17 to $127 per ton, then dropped to $84 in late 1983 and stood at $94 in the spring of 1988 [BSC88b]. Table 9-2 shows the sulfur export prices between 1972 and 1988.

Forecasts of Mined Sulfur Supply -- D.A. Buckingham, with the U.S. Bureau of Mines and with assistance from Jacobs Engineering Co. (the parent company of Zellars-Williams), estimated in 1986 the availability of mined elemental sulfur and pyrite in market economy countries through the year 2005. This study focused on 36 developed operations. Buckingham projected that 152 million tons of elemental sulfur are available throughout the world at less than $90 per ton (January 1984 dollars) [Bu86]. Approximately 23 percent of these developed reserves, 34.8 million tons, are in the United States. In a 1988 article, Buckingham revised his estimate for the United States upward to 41.6 million tons at essentially the same cost, $93.50 (January 1986 dollars). Another 19.9 million tons are available at a cost of less than $136 per ton (January 1986 dollars) [Bu88].

In 1986, U.S. Frasch mines produced slightly more than 4 million tons of sulfur [Mo87]. At this rate of production, developed reserves would be depleted in approximately fifteen years. Buckingham projects that production from these reserves will decline steadily. Production levels will decline to 2.5 million tons in the late 1990s and will be below 500,000 tons by year 2001. These projections indicate that unless new mines are developed in the near future, domestic Frasch mines in the future will supply only a small portion of U.S. sulfur demand.

In terms of world supplies of sulfur, pyrite is a more important source than elemental sulfur from Frasch mines. Buckingham estimates that 256 million tons are available at production costs of $43 per ton or less (January 1984 dollars) [Bu86]. This cost corresponds to the 1984 market price of pyrite concentrate. Pyrite generally sells for approximately one third the price per ton of elemental sulfur. In addition, a portion of pyrite is available as a co-product. In these cases, the value of the other metals found with the pyrite cover some or all of the mining costs and the pyrite could be economically mined at a lower price level [Tu87].

The Bureau of Mines research described in the preceding paragraphs presents only a partial picture of the availability of elemental sulfur from Frasch mines and sulfuric acid from pyrite mines. Because of the narrow focus of the study on developed deposits, nearly 90 percent of the sulfur resources identified by the U.S. Geological Survey were not examined [Tu87]. Insufficient data, however, are available with which to make production cost estimates for these other reserves.

Forecasts of Recovered Sulfur Production -- Because recovered sulfur is a by-product, forecasts of the supply of recovered sulfur are neccessarly based on forecasts of the production of petroleum, natural gas and other products from which sulfur is recovered. Although forecasts of these products are available, it is not clear to industry experts what ratio of sweet to sour petroleum and natural gas will be used in the U.S. or elsewhere [Mo88b]. Consequently, authorities in the sulfur field avoid forecasting the supply of recovered sulfur.

Only approximately 15 percent of U.S. natural gas reserves are sour, when sour is defined as gas containing by volume 5 percent or more H_2S content. Such an estimate would represent a reserve of 108 million tons of recoverable sulfur. Crude oil processed in the U.S. has gone from 65 percent sweet in 1964 to only 40 percent in 1980 [BSC85h]. The trend toward a higher proportion of sour oil has continued in the 1980s. Table 9-6 shows the trend in sulfur production from petroleum and natural gas between 1980 and 1985. For petroleum refining, the trend has been towards a steadily higher ratio of sulfur to oil. Between 1980 and 1985 the quantity of sulfur recovered for the same quantity of oil increased by 45 percent. In the case of natural gas, the trend has been erratic with the ratio of sulfur to gas increasing 61 percent between 1980 and 1983 but dropping slightly in 1984 and then rising slightly in 1985 [Mo85]. The Department of Energy projects that in the year 2000, 6,679.5 million barrels of oil will be refined and 20.02 trillion cubic feet of natural gas will be in

Table 9-6: U.S. Sulfur Recovery Trends 1980-1985

RATIO OF SULFUR PRODUCED PER UNIT REFINED	1980	1981	1982	1983	1984	1985
OIL \1	0.4694	0.5014	0.5643	0.6033	0.6311	0.6787
NATURAL GAS \2	87.6	98.7	105.8	141.0	132.1	137.7

\1 Calculated by dividing recovered sulfur at petroleum refineries by crude oil receipts at refinery. Units are thousand metric tons of sulfur recovered per million barrels of oil refined.

\2 Calculated by dividing recovered sulfur at natural gas plants by natural gas, marketed product. Units are thousand metric tons of sulfur recovered per trillion cubic feet of gas refined.

SOURCE: Statistical Abstract of the U.S., Department of Commerce, various years; Minerals Yearbook, Bureau of Mines, various years.

supply [EIA88]. These forecasts imply a supply of approximately 7.2 million tons of recovered sulfur in the year 2000[3], compared to 5.8 million tons in 1986.

The U.S.S.R. should become a major exporter in the near future as it completes development of the Astrakhan natural gas development. The addition of the U.S.S.R. as a major exporter will lower Morocco sulfur costs. In 1985, Morocco imported 65 percent of its sulfur from Canada and 19 percent from the U.S. at much higher transportation costs than it would experience with the U.S.S.R [BSC86].

Summary -- There is little risk of a shortage of sulfur in the next several decades. However, sources of supply will change. In the past decade, the U.S. phosphate industry has had a competitive advantage because of relatively low priced and nearby sulfur supplies. In the next several decades this advantage will end and most U.S. phosphoric acid producers will experience relatively higher sulfur costs. At the same time, the relative price of sulfur for Morocco and other North African producers will decline as sulfur supplies increase in nearby regions.

9.2.1.2 **Products**

In 1987, the U.S. produced 9.5 million metric tons of phosphoric acid. Wet-process phosphoric acid (WPPA) comprised 94 percent of this production. Fertilizer uses claimed 89 percent of all phosphoric acid production and a higher proportion of WPPA production. The remaining 5 percent was used in the production of animal feed supplement and other food additives. About 72 percent of the WPPA used in fertilizers was used to produce mixed phosphate fertilizers; the rest went into direct applications (fertilizer products that have primarily one plant nutrient) [DOC87]. Mixed fertilizers have two or more nutrients. Diammonium phosphate (DAP), for example, is a mixed fertilizer with 18 percent nitrogen and 46 percent phosphate [Vr86]. A chart of intermediate and end products of the WPPA industry is provided in Figure 9-2.

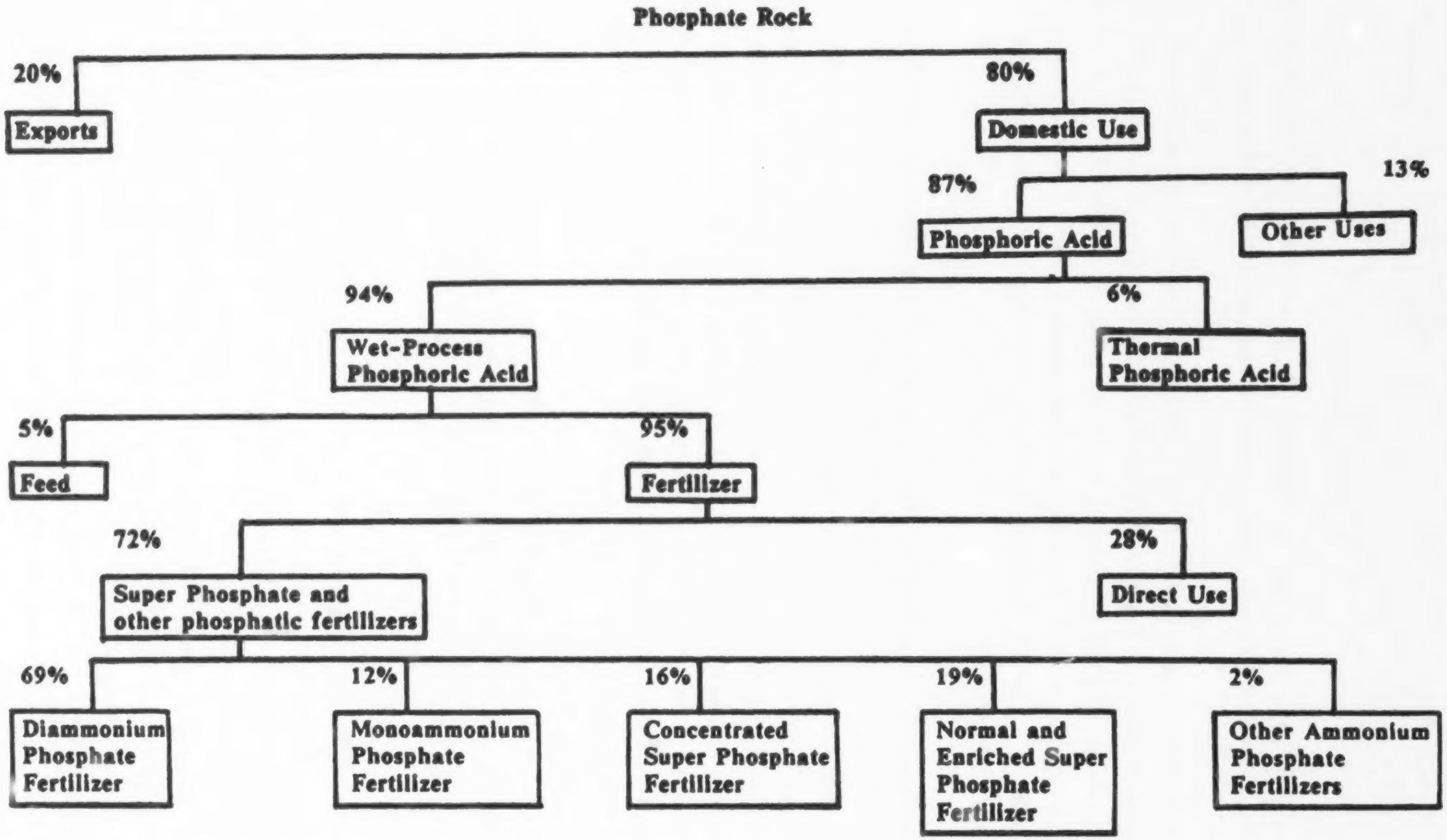
9.2.1.3 **U.S. Phosphate Producers**

The fertilizer industry is devoted to the production and marketing of three basic nutrients: nitrogen, potassium and phosphate. The scope of the fertilizer industry includes production of ammonia,

---

[3] This estimate uses the most recent ratios of sulfur recovered to fuel refined. Since, as noted, these ratios are increasing, this should be regarded as a conservative forecast.

Figure 9-2: Uses for Phosphoric Acid, 1985-86


Phosphate Rock
20%
Exports
80%
Domestic Use
87%
Phosphoric Acid
13%
Other Uses
94%
Wet-Process Phosphoric Acid
6%
Thermal Phosphoric Acid
5%
Feed
95%
Fertilizer
72%
Super Phosphate and other phosphatic fertilizers
28%
Direct Use
69%
Diammonium Phosphate Fertilizer
12%
Monoammonium Phosphate Fertilizer
16%
Concentrated Super Phosphate Fertilizer
19%
Normal and Enriched Super Phosphate Fertilizer
2%
Other Ammonium Phosphate Fertilizers

Source: "Inorganic Fertilizer Materials and Related Products" Current Industrial Reports, October 1986; Jack Faucett Associates.

ammonium nitrate, urea, phosphates (diammonium phosphate, triple superphosphate, and others), nitrophosphates, mixed plant foods, superphosphates, phosphoric acid and potash.

According to the most recent Department of Commerce census, the phosphate industry had $3.6 billion in assets in phosphate fertilizer manufacturing facilities [DOC86b] and another $3.3 billion in phosphate rock mines [DOC82b]. Table 9-7 shows other information from the industry census. Phosphoric acid producers are generally not single-product firms. Few companies are totally dependent on fertilizer production; most fertilizer production is a subsidiary activity of a large, diversified corporation.

Most of these companies are vertically integrated from phosphate rock production to fertilizer production. The largest WPPA producers are also among the largest phosphate rock producers. Each of the largest phosphate rock producers owns basic fertilizer production facilities either directly or through equity interest in chemical producing companies. Some also have interests in sulfur reserves. Table 9-8 gives a geographical breakdown of the major phosphate fertilizer producers and their capacities to mine phosphate rock and produce phosphoric acid and several phosphate fertilizers. In many cases the production facilities are linked in a single plant. Where it is clear that mines and plants are closely linked, Table 9-8 lists the facilities together. This information is summarized in Table 9-9.

In 1984, 22 U.S. companies accounted for 33 percent of world phosphate rock production; 12 companies in Florida and one in North Carolina produced 87 percent of the U.S. total [Ga85]. Most of the fertilizer production plants in Florida are located in Polk and Hillsborough counties in Central Florida.

Most chemical fertilizer producers have been operating below capacity since the early 1980s, at 79 percent capacity for WPPA on average. The lowest rates occurred in 1982, when the industry averaged 63 percent of capacity [TFI86B]. This information is summarized in Table 9-10.

The Fertilizer Institute sponsors periodic surveys of member companies to collect general financial information for the integrated fertilizer manufacturing industry. TFI survey results show that the return on total assets was less than one percent, either positive or negative in 1982, 1983, and 1985. In 1984 and 1986, the return on total assets was a positive 5 percent and a negative 5 percent, respectively [TFI87b]. These low rates of return have been blamed on poor demand for fertilizer and on excess capacity.

Table 9-7: Financial Condition of Phosphate Industry

	PHOSPHATE FERTILIZER MANUFACTURING (1985 dollars)	PHOSPHATE MINING (1982 dollars)
	(thousands)	
CAPITAL ASSETS AND EXPENDITURES		
ASSETS	3,639,000 \a	3,301,700 \b
NEW CAPITAL EXPENDITURES	171,700 \a	223,000 \b
DEPRECIATION	244,600 \a	144,500 \b
RETIREMENTS AND USED ASSETS \e	180,100 \a	17,500 \b
OPERATING EXPENDITURES		
PAYROLL&BENIFITS	337,200 \d	267,700 \c
RENTS	13,000 \a	9,800 \c
SUPPLIES & MATERIALS	3,576,600 \d	540,000 \c
FUEL	--------	161,400 \c
EXPENSED MINERAL RIGHTS	--------	77,500 \c

a) 1985 Annual Survey of Manufacturers, Expenditures for Plant and Equipment, Table 2, page.4-30.
b) 1982 Census of Mineral Industries, Gross Book Value of Depreciable Assets, Table 2, page 2-4 and 2-5
c) 1982 Census of Mineral Industries, General Summary, Table 7, page 1-28.
d) 1984 Annual Survey of Manufacturers. Statistics for Industry Groups and Industries, Table 2, p. 1-14.
e) Includes assets that are sold.

Table 9-8: Producers of Phosphate Rock, Wet Process Phosphoric Acid and Phosphate Fertilizer.

(Thousand Metric Tons Per Year)

COMPANY	LOCATION	PLANT STATUS	PHOSPHATE ROCK	PHOSPHORIC ACID	AMMONIUM PHOSPHATE	CONCENTRATED SUPERPHOSPHATE
Freeport McMoran	Donaldsonville, LA	OPERATING		430.8	816.3	
	Pierce, Fl	OPERATING		380.9	75.3	250.3
	Uncle Sam, LA	OPERATING		798.2		
	Fort Green, FL	OPERATING	2,721.0			
	Payne Creek, FL	OPERATING	2,721.0			
	Taft, LA	PLANNED			335.6	
Arcadian Corp	Geismar, LA	OPERATING		163.3	125.2	
Bartow Chem (W. R. Grace)	Bartow, Fl	OPERATING		375.5		
CF Industries	Plant City, Fl	EXPANSION		789.1		
	Plant City, FL	OPERATING			544.2	367.3
Chevron Chemical Co	Rock Springs, WY	OPERATING		181.4	181.4	
	Vernal, UT	OPERATING	1,179.1			
Conserv (Agrimont)	Nichols, Fl	OPERATING		181.4	172.3	
Cominco	Garrison, MT	OPERATING	249.4			
Estech, Inc	Watson Mine, FL	OPERATING	907.0			
Farmland Industries	Pierce, Fl	OPERATING		520.6	304.8	
Florida Phosphate Corp	Lakeland, FL	OPERATING	108.8			
Ford Motor Co	Dearborn, MI	OPERATING			9.1	
Gardinier	Tampa, Fl	OPERATING		653.0	430.8	272.1
	Fort Meade, FL	OPERATING	2,721.0			
Grace, W. R. & Co	Bartow, Fl	OPERATING		281.2	648.5	113.4
	Hooker's Prairie, FL	OPERATING	2,721.0			
	Four Corners, FL	OPERATING	4,988.5			
IMC Fertilizer, Inc	Bonnie, Fl	OPERATING		1,541.9	1,224.5	163.3
	Bartow, FL	OPERATING	11,337.5		648.5	
	Brewster, FL	OPERATING	4,535.0			
Kaiser Steel Corp	Fontana, CA	OPERATING			13.6	
Mobil Chemical Co	Fort Meade, FL	OPERATING	2,902.4			
	Nichols, FL	OPERATING	1,360.5			
	Pasadena, TX	OPERATING		217.7	208.6	
Monsanto Co	Henry, ID	OPERATING	907.0			
Nu-West Industries	Conda, ID	OPERATING		281.2	189.6	
	Dry Valley, ID	OPERATING	1,360.5			
	Wingate Creek, FL	PLANNED	1,814.0			
	Pascagoula, MS	OPERATING		308.4	312.9	
Occidental Ag Chemicals	White Springs, Fl	OPERATING	4,988.5	1,015.8	317.5	
	Columbia, TN	OPERATING	907.0			
Presnell Phosphates	Columbia, TN	OPERATING	453.5			
Royster Co	Mulberry, FL	EXPANSION		226.8	249.4	
	Piney Point, Fl	OPERATING		172.3	166.9	
Simplot, J. R.	Pocatello, ID	EXPANSION		317.5	173.2	40.8
	Fort Hall, ID	OPERATING	907.0			
	Smoky Canyon, WY	OPERATING	1,814.0			
Stauffer Chemical Co	Leefe, WY	OPERATING	453.5			
	Mt Pleasant, TN	OPERATING	544.2			
	Wooley Valley, ID	OPERATING	680.3			
Tennessee Valley Authority	Muscle Shoals, AL	OPERATING			18.1	
Texasgulf (Aquitaine)	Lee Creek, NC	EXPANSON	5,079.2	1,020.0	348.3	299.3
USS Agri-Chemicals	Bartow, FL	OPERATING			219.5	109.7
	Fort Meade, Fl	EXPANSION	1,814.0	426.3		
Total United States			60,174.9	9,263.2	7,734.0	1,616.3

For completeness, this table includes companies that only produce phosphate rock and do not produce phosphoric acid.

SOURCE: National Fertilizer Development Center, Tennessee Valley Authority, "North American Fertilizer Capacity Data," pp. 7-10, July 1988.

Table 9-9: Capacities of Major Phosphoric Acid Producers Estimates for 1988/89

(Metric Tons Per Year)

COMPANIES	PHOSPHATE ROCK MINING	PHOSPHORIC ACID CAPACITY
FREEPORT MCMORAN	5,443,200	1,610,280
AGRIMONT		181,440
ARCADIAN CORP.		163,296
CF INDUSTRIES		789,264
CHEVRON CHEMICAL	1,179,360	181,440
FARMLAND INDUSTRIES INC.		520,733
GARDINIER INC.	2,721,600	653,184
W.R.GRACE & CO. (1)	7,711,200	566,093
INTERNATIONAL MINERALS & CHEMICALS CORP.	15,872,500	1,541,900
MOBIL CORPORATION (2)	4,263,840	217,728
NU-WEST INDUSTRIES	3,175,200	589,680
OCCIDENTAL CHEMICAL AGRICULTURAL PRODUCTS	5,896,800	1,016,064
ROYSTER CO.		399,168
J.R. SIMPLOT CO. MINERALS AND CHEMICALS DIVISION	2,721,600	317,520
TEXASGULF	5,080,320	1,152,144
USS AGRI-CHEMICALS	1,814,400	426,384
OTHER (3)	4,294,880	
TOTAL	60,174,900	10,326,318

Source: National Fertilizer Development Center, North American Fertilizer Capacity Data, July 1988.

1) Includes Bartow Chemical phosphoric acid capacity owned by W.R. Grace.

2) Includes Mobil Mining and Minerals Phosphates Minerals Group and Mobil Chemical Company.

3) Companies which produce phosphate rock but do not produce phosphoric acid are not shown on this table.

Table 9-10: Operating Rates for U.S. Fertilizer Producers (percentage of full capacity)

	1981		1982		1983		1984		1985		
	Jan-June	July-Dec	Jan-June	July-Dec	Jan-June	July-Dec	Jan-June	July-Dec	Jan-June	July-Dec	Average
Phosphoric Acid, Super	50.3	74.3	55.4	59.8	57.1	70.7	72.2	85.8	75.1	87.3	68.8
Phosphoric Acid, Wet Process	93.3	78.3	63.4	63.2	73.2	79.5	84.2	87.2	85.1	74.2	79.2
Concentrated Super, Granular	92.0	69.0	47.3	71.6	73.1	83.3	67.3	73.3	76.2	80.8	73.4
Diammonium Phosphate	98.1	73.2	58.6	59.8	70.2	75.4	82.6	81.6	82.1	68.3	75.0
Monammonium Phosphate	83.4	74.8	61.2	71.8	74.1	83.3	86.8	82.3	82.4	60.8	76.1

Source: The Fertilizer Institute

In order to cut losses, firms have been re-organizing and consolidating. Beker has filed for bankruptcy under Chapter 11 and no longer operates any plants. Over 17 percent of U.S. capacity has either been recently sold or is closed awaiting higher prices. Another 17 percent of current capacity is somewhat insulated from price shifts because it is owned by farm cooperatives. Following is a short description of the corporate structure and activities of those publicly owned chemical manufacturers with WPPA operating capacity of over 500,000 tons[4]. Four privately owned companies also have a capacity over 500,000 tons. They are C.F. Industries, Gardinier Inc., Nu-West Industries, and Occidental Chemical Agricultural Products, Inc. Data are not available to describe their financial status.

W.R. Grace and Company -- Grace is a highly diversified company with a 624,000 ton capacity in phosphoric acid production and 8,500,000 ton capacity in phosphoric rock mining. Grace had sales of $3.7 billion in 1986, with $2.5 billion in specialty chemicals. Grace went through major restructuring in 1986 and had losses from continuing operations of $324 million in 1986.

As part of its restructuring, Grace has announced its intent to divest its agricultural chemicals business and in 1986 it set aside $221 million to cover losses from that move [Ri87]. Grace closed its Four Corners plant during the 1986/1987 season. As of July 1988, however, a report from the Tennessee Valley Authority shows Grace operating its wet process acid plants in Hooker's Prairie and in Four Corners, both in Florida [TVA88]. *Green Markets* reported in March 1988 that Grace had sold more of its retail fertilizer operation and plans to sell the remainder of its fertilizer business by the end of 1988 [GM88d].

Farmland Industries, Inc. -- Farmland Industries, Inc., is a regional agricultural cooperative based in Kansas City, Missouri. Farmland is owned by 2,186 local cooperatives and serves a federated network in 19 midwestern states and Canada. Farmland had $2.6 billion in sales in 1987 and profits of $55.2 million. Petroleum, food marketing, agricultural chemicals and feed are its four principal sectors. Agricultural chemicals represented 20.2 percent of total sales. Sales of all agricultural chemicals were $528.5 million in 1987, down from $573.6 million in 1986. This sector had operating income of $1.3 million, after a loss of $38.4 million in 1986 and $49 million in 1983.

Farmland has a phosphoric acid operating capacity of 574,000 tons in Pierce, Florida, representing 5 percent of the entire industry capacity. Farmland has a phosphate rock mining capacity of 2 million tons; this operation was closed as of January 1988. Its total fertilizer capacity is 3.6 million tons, including operations in ammonia, ammonia nitrate and urea. In addition, Farmland has a proposed phosphate mining operation in Hardee County, Florida with a 40 million ton reserve [TVA88].

---

[4] Unless otherwise indicated, the information for each of the companies that is provided in this section came from annual corporate reports for the years 1982 to 1987.

In 1987, Farmland sold 3.58 million short tons of phosphate and nitrogen fertilizers. Unit sales increased in 1987 by 25 percent, but at lower prices so that revenue from fertilizer sales increased only $13.9 million. Growth came from an expansion of sales to industry and from exports. Sales to non-members represented 27 percent of total sales of agricultural chemicals.

In some years, losses in phosphate operation have been fully offset by gains in other agricultural chemicals. While Farmland had operating income of $2.7 million for agricultural chemicals in 1985, the phosphate division lost $42 million in that year. In 1985, Farmland closed a sulfur mine that services phosphate production and charged the $3.7 million cost against phosphate operations. In 1984, phosphate operations lost $12 million while agricultural chemicals overall had positive operating income of $38 million. In 1983, total phosphate losses amounted to $8.3 million.

AMAX -- AMAX is a diversified energy development and minerals company with extensive operations in aluminum, coal and molybdenum as well as many other minerals. AMAX had modest and successful operations in phosphate and potash throughout the 1970s, with average sales between 1973 and 1979 of $43.7 million. AMAX expanded the phosphate operations with a purchase of the Big Four mine in Florida in July 1980. Beginning in 1982, AMAX phosphate operations have been consistently unprofitable; in 1984 AMAX announced its desire to get out of the business.

In 1984, AMAX began to phase out the agricultural chemicals segment and set aside $195 million for losses on properties and investments in that segment. In December of 1985, AMAX had a tentative agreement to sell its phosphate operation for $40 million. However, a July 1988 listing of production capacities by the Tennessee Valley Authority continues to show AMAX with a closed 2.5 million ton capacity phosphate rock mine in Big Four but lists its 190,000 ton phosphoric acid capacity in Piney Point, Florida as sold [TVA88]. Because all AMAX facilities have ceased operations, the firm is not included in Table 9-8.

Total sales for AMAX in 1986 were $1.3 billion, with earnings of $89.4 million. Because of changes in the organization of the company annual report, it is not possible to reliably analyze the change in total sales during the mid-1980s. The 1986 annual report gave 1985 sales of $1.2 billion with an operating loss of $106.5 million. Losses in that division during those years were $17.3, $214.4 and $17.1 million, respectively.

International Minerals and Chemicals (IMC) -- IMC is a diversified chemical producer. Up to 1986, its sales were concentrated in animal and fertilizer products. That year it acquired Mallinckrodt, Inc., a producer of medical products, drugs, chemicals, laboratory reagents for $700 million. Fertilizer sales dominate IMC financial activity. In 1986, IMC fertilizer sales represented 53 percent of total net sales of $1.6 billion. Animal products, including feed grade phosphate and other feed additives, and Mallinckrodt, Inc. represented 11 percent and 40 percent, respectively. Phosphate chemicals represented 41 percent of total IMC fertilizer sales.

In 1987, IMC owned or operated 15 percent of U.S. phosphoric acid capacity. It owns 25 percent of the U.S. phosphate rock mining capacity in Florida.

Most of the WPPA is produced at its New Wales, Florida facility (1.7 million tons of WPPA manufacturing capacity). The phosphate rock is mined at a nearby plant. In 1987, 45 percent of its New Wales production was sold domestically, 38 percent was exported and 17 percent was used by IMC to manufacture its own brand of fertilizer. The plant operated at 85 percent capacity in 1987. In 1986, IMC reported operating losses of $61.0 million, but by 1987 sales had picked up, yielding $67.1 million in operating profits. Nevertheless, IMC fertilizer sales have been flat since 1986, reflecting lower average product prices.

IMC has also been cutting operating costs. It reported developing a process to reduce the amount of sulfuric acid needed per unit of P_2O_5 product. It has sold most of its retail outlets in the midwest. IMC Fertilizer Group employment has been reduced to 5,525 in 1986 from 6,687 in 1981.

Texasgulf Chemicals Company -- Texasgulf Chemicals Company has operations primarily in phosphate and sulfur, but also in potash and soda ash. Texasgulf is a division of Elf Aquitaine, S.A. (EAI). EAI is a U.S. subsidiary of Elf, a multinational company based in Paris with operations in oil, gas, chemicals and pharmaceuticals. EAI's 1986 sales were $1.7 billion. The sales for Texasgulf were $474, $461 and $547 million in 1984, 1985 and 1986, respectively. Texasgulf had assets of $2.2 billion in 1986.

Texasgulf has a phosphoric acid plant in Lee Creek, North Carolina, with a capacity of 1,270,000 tons, 10 percent of U.S. capacity. It also has a phosphoric mining capacity of 5.6 million tons. The Lee Creek plant was expanded, beginning in the mid-1970s. The expansion was completed in 1986. This plant is unusual in a number of ways. It disposes of its gypsum by blending it with clay and returning it to the mine. It also removes the overburden in its Lee Creek mine with dredges.

The Lee Creek wet-process plant produces a high quality phosphoric acid that has been sold for industrial grade acid and for animal feed. Texasgulf produces several types of calcium phosphate animal feeds in North Carolina and Nebraska.

Freeport-McMoRan, Inc. -- Freeport-McMoRan, Inc. (FMI) has operations in agricultural minerals, oil, gas, geothermal energy and uranium. Revenues in 1986 totaled $629.7 million. Because of a $277 million write down of oil and gas related assets, its operating loss in 1986 was $147 million. Revenues were $722 million and $842 million in 1985 and 1984, respectively, and operating income was a positive $156 million and $170 million, respectively. The agricultural minerals sector earned $39 million in 1986 and $62 million in 1985.

FMI's sulfur operations are as important as its phosphate operations and depend heavily on demand for phosphates. Sales of phosphate and sulfur in 1986 were $161.5 and $161.3 million, respectively. In mid-1986, FMI conveyed its sulfur, phosphate and geothermal properties, among others, to Freeport-McMoRan Resource Partners, Limited Partnership (FRP) and approximately 19 percent of FRP was sold in a public offering.

FMI produces phosphoric acid in its Uncle Sam plant in Louisiana. This plant produced 715,500 tons in 1986 and 714,000 tons in 1985. FMI produced 332,200 tons of DAP in 1986.

Freeport Uranium Recovery Company produces uranium oxide at recovery facilities at the Uncle Sam plant and at the Agrico plant in Donaldsonville, Louisiana. These operations produced 1,720,000 pounds of uranium oxide in 1983.

The Uncle Sam plant has limited space to store its phosphogypsum. As a consequence, FMI has worked with Davy McKee and the Florida Institute of Phosphate Research to test technology to recycle phosphogypsum into sulfuric acid and aggregate. FMI is spending $3 to $4 million on a demonstration plant at Uncle Sam that will consume 33 tons of phosphogypsum per day [LI88]. Construction of the plant was halted in the summer of 1987 because of engineering problems, but was resumed in the spring of 1988. An FMI spokesperson said that the plant will begin operation in the early fall of 1988 [GM88d].

The FMI phosphate rock mine was shut down in April 1982, because of weak demand for phosphate rock, and reopened in April 1984. During this time, FMI purchased rock from others. At the end of 1986, FMI held phosphate rock proved and probable reserves of 14 million tons and sulphur proved and probable reserves of 10.5 million long tons.

FMI agreed in principle to purchase most of the assets of Agrico Chemical Company, a subsidiary of The Williams Company, for $250 million cash and another $100 to $250 million in cash or other compensation. Agrico has extensive operations in Florida and Louisiana in phosphate mines, phosphoric acid, and phosphate fertilizer plants.

9.2.1.4 Employment

In 1988, approximately 10,900 persons were employed directly by the phosphoric acid and phosphate fertilizer industry [DOC88a]. Since 1981, employment in the industry has decreased at an average annual compound rate of 3.6 percent. Table 9-11 provides employment and earnings trends from 1984 to 1988. Employment increased during the 1970s and peaked in 1981 at 15,700 workers [DOC84].

Phosphoric acid production is not a labor intensive industry. Operating labor represents less than 2 percent of total costs, according to TFI. Operating labor represents 9 percent of the cost of mining phosphate rock [TFI87c].

Direct employment represents only a part of the employment that could be affected by a change in demand for WPPA. Others affected would include phosphate rock plant workers, miners and agricultural chemical manufacturers and retailers. The phosphate rock mining industry employed 7,800 people in 1982 [DOC82b].

The 1982 drop in fertilizer sales led to the reported firing of nearly 5,000 workers in phosphate producing plants. At least another 25,000 in businesses that depended on phosphate, such as engineering firms and port workers, lost jobs as well. This reduction in sales provided a graphic representation of the importance of the phosphate fertilizer industry for local economies in the U.S. For example, the drop in fertilizer manufacturing activities hurt Tampa Electric which supplies power to most of Florida phosphate companies and the Tampa Port Authority which handles over 87 percent of all WPPA exported from the United States [Te87,FF85].

Table 9-11: Employment in the Phosphate Industry, (thousands)

	1984	1985	1986/1	1987/1	1988/2	Compound Annual Percent Change 1972-85	Compound Annual Percent Change 1980-85
Total Employment	13	13	11.2	10.9	10.9	-1	-3.6
Production Workers	8.9	8.7	7.8	7.8	7.8	1.6	-4.6
Average Hourly Wage ($)	11.54	12.12	12.73	13.75	--	8.9	8

Notes: /1 Estimated.
/2 Forecast.

Source: International Trade Commission, U.S. Department of Commerce, U.S. Industrial Outlook 1988, January 1988, p.14-3.

9.2.2 Characteristics of Phosphoric Acid Demand

The demand for WPPA is largely determined by the demand for phosphate fertilizers. Widespread chemical fertilizer use is a relatively recent phenomenon. In the early- to mid-1960's world and domestic fertilizer use expanded rapidly. The "Green Revolution" of this time brought high yielding varieties of grain crops which required more intensive fertilizer application than did traditional varieties [Te87]. Between 1970 and 1983, fertilizer use per acre grew about 271 percent in low income countries and 107 percent in middle income countries. The largest per acre increases were reported by India (a 246 percent increase) and the People's Republic of China (a 332 percent increase) [WB86].

Fertilizer use has not increased evenly for all nutrients. Nitrogen use has increased more rapidly than have phosphate and potassium use, due primarily to the favorable response of crop yield to nitrogenous fertilizer. The share of phosphates in total plant nutrient consumption in the U.S. has declined from about 33 percent in 1960 to about 23 percent in 1986 [Vr86]. Figure 9-3 traces the growth of plant nutrient use in the United States.

Given its relatively small share of domestic and world phosphate use (about 5 percent, see figure 9-2), fluctuations in animal feed consumption are of limited importance to the phosphate industry. Consumption of phosphate supplements for animal feeds and other minor uses has varied in the past decade, reaching a high of 661,920 tons in 1984 [DOC87]. Demand for phosphate animal feed supplements dropped because of a decrease in the recommended supplement ratios and the increased availability of a substitute, fish meal. Almost all phosphate supplements are in the calcium phosphate form. Exports of phosphate supplements represented only 5 to 6 percent of 1983 domestic production [SRI85].

9.2.2.1 Determinants of Domestic Demand

Demand for WPPA in the United States depends directly on those factors which affect the demand for fertilizer. Some of these factors are acreage planted, application rates, crop prices, prices of other fertilizers, farm income, population, and weather. It is important to understand how these are interrelated in order to understand what has determined the growth of phosphate fertilizer demand in the 1980s and the soft prices which have characterized the domestic and international markets.

The consumption of any agricultural nutrient depends upon the acreage of different crops and the application rates on specific crops. Some crops use more phosphate than others and respond much better to one type of fertilizer than to another. Food grain production requires lower proportions of nutrients per acre than does feed grain production [WH88]. In the United States, corn uses the most phosphate fertilizer per acre of the major crops, while soybeans and wheat use the least [Vr86].

Planting pattern changes on U.S. farms have favored growth of phosphate demand. Almost every year since 1964, more acres have been harvested with corn than any other major crop including wheat, cotton and soybeans. In addition, a greater proportion of corn acreage has been fertilized over the years than any other major crop. Approximately 85 percent of the corn acreage harvested in 1987 received phosphate applications, compared to roughly 50 percent of cotton, 48 percent of wheat and 29 percent of soybean acreage. In fact, U.S. farms used more fertilizer of all types on corn than on any other crop. Almost 98 percent of corn planted received some type of fertilizer in 1985, compared to about 75 percent of the wheat planted and 38 percent of the soybeans [Vr86]. Finally, major crops (which include corn, wheat, soybeans and cotton) are fertilized more intensively than non-major crops (such as sorghum, oats, barley, rice, rye, peanuts, potatoes). The percentage of acres planted to major crops has been increasing since 1964, while acreage of non-major crops harvested decreased 13 percent between 1964 and 1985 [WH88].

Application rates have been an important factor influencing fertilizer demand in the U.S. Use on corn and other crops increased dramatically between 1964 and 1980, due more to higher application rates than to an increase in the proportion of acreage either harvested or fertilized. For example, while corn acreage increased by about 36 percent between 1964 and 1980, nitrogen use rose 272 percent, phosphate use increased 118 percent and potassium increased 225 percent. In the early 1980s, phosphate application per acre began declining [Vr86][5]. Since 1985, the rate of phosphate fertilizer use has been linked more closely to increases in acreage planted and fertilized than to application rates [Vr86].

Since 1983, the acreage of major crops planted has depended in large part on U.S. government price support programs. Under the payment-in-kind program of 1983, U.S. farmers agreed not to grow crops on a total of 77 million acres (37 percent of the land sowed with grains, cotton and rice). In return for idling their land, farmers got up to 80 percent of the quantity of grain they would normally have grown. The in-kind payments came from crops that had been stored by the government [Wb86].

---

[5] The decline in phosphate application rates is generally explained as follows: Unlike nitrogen and potash, any phosphate not used by the crop remains in the soil and is available for a future crop. As this fact became known, farmers decreased phosphate use. Also, new tilling and crop management practices have allowed farmers to increase yields using less phosphate (see E.A. Harre, "Emerging Trends in World Phosphate Market," National Fertilizer Development Center, Circular No. Z-228, September 1987).

In 1985, the Food Security Act was passed to increase grain exports, reduce inventories and support farm income [St85]. Through a variety of different measures, including set-asides, paid land diversions and the Long-Term Conservation Reserve, U.S. crop-planted acreage decreased from 363 million acres in 1981 to 305 million acres in 1987 [WH87]. Farmers have responded to the acreage reduction by using somewhat higher quantities of fertilizer per acre on the remaining acreage but in general the acreage reduction has led to a reduction in demand for phosphate fertilizers.

These programs, aided by dry weather and the drop in the number of operating farms between 1985 and 1987, have begun to reduce the reserves of surplus agricultural commodities accumulated by the U.S. Department of Agriculture (USDA). In 1988, corn stocks are expected to fall by 400 million bushels, wheat stocks by 200 million bushels, and soybean stocks by 20 million bushels [WH87].

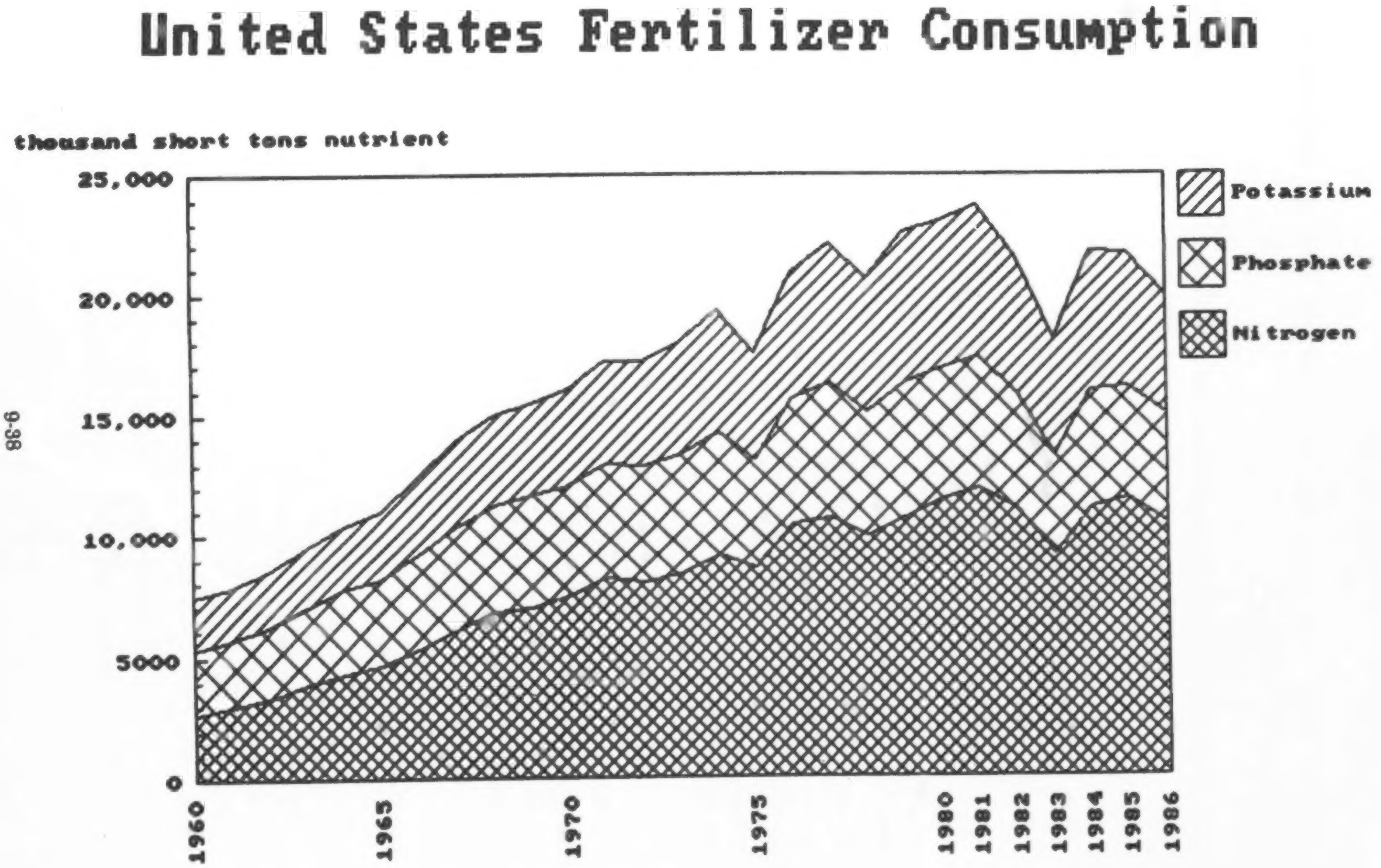
Fertilizer and crop prices also affect the demand for plant nutrients. In general, as the fertilizer price to crop price ratio decreases, the application rate per acre increases. As crop prices rise relative to fertilizer prices, farmers wish to increase yields and hence increase fertilizer use.

Because the full effect of reduced phosphate application does not occur immediately, farmers may be highly-responsive to fertilizer price increases in the short run. Phosphate is depleted from the soil more slowly than nitrogen, for example, and the effects of decreased phosphate application only become apparent once the level in the soil is depleted. It is estimated that a 10 percent reduction in phosphate application in the first year will reduce corn yields by 3 percent in the first year and 4 percent in the third year. Wheat yields are more sensitive in the long run: a 10 percent reduction in phosphate application will reduce yields 1 percent in the first year but by 7 percent in the third year [GAO79].

Fertilizers represent only about 7 percent of total farm costs; phosphate fertilizers account for about 1 percent of total farm costs. On the other hand, fertilizers account for a large part of the variable costs of crop production: 50 percent of wheat production costs, 35 percent of corn costs and 20 percent of soybean costs [GAO79].

Finally, fertilizer use is also affected by changes in farm income. Net farm income, in 1967 dollars, was lower in 1985, $9.5 billion, than in 1971, $12.4 billion. Yet this still represented an improvement

Figure 9-3



source: USDA

over the 1983 low of $4.4 billion [USD87e]. In 1986, over 33 percent of all net farm income came from government payments. The heavy dependence of farmers on government programs has increased their responsiveness to acreage reduction policies [Ri87].

9.2.2.2 Determinants of Foreign Demand

Foreign demand for WPPA depends on the same variables described in the preceding section: population, acreage, crop variety, fertilizer application rates, and crop and fertilizer prices. World plant nutrient consumption has been growing at an average annual compound rate of 4.2 percent since 1975, though in 1986 consumption of fertilizer dropped about 4 percent from the 1985 high of 34.29 million metric tons [TFI86b]. Phosphate fertilizer consumption accounts for about 26 percent of total world nutrient consumption and increased at an annual compound rate of 3 percent between 1975 and 1985 [TFI86b].

Fertilizer use patterns have varied considerably from one region of the world to another. Fertilizer demand in less developed countries (LDCs) has tended to grow much faster than in the industrialized countries, but fertilizer use per acre is still, in absolute terms, much greater in the industrialized world [WH87].

According to each of the fertilizer demand forecasting models examined for this report, population growth is one of the most important factors leading to growth in the volume of world grain trade and, indirectly, affecting acreage and fertilizer application rates. Population growth in LDCs has historically been 1 to 2 percentage points higher than in high-income economies. But high population growth rates alone are not enough to guarantee high grain demand. Grain demand in low- and middle-income countries has been sluggish since 1980 due to growing debt problems and the relatively high value of the U.S. dollar *vis à vis* these currencies. In fact, world grain trade has stagnated or declined in recent years, in contrast to the 75 percent increase in trade during the 1970s, due in large part to the adverse economic conditions facing these countries.

Acreage expansion seems to have played a limited role in the expansion of world fertilizer demand. World acreage, which had declined since 1982, stabilized by 1987. While acreage expansion rates have differed regionally, overall expansion has been limited. In North America and Europe, farm subsidy policies and acreage reduction programs have caused acreage planted and harvested to decline since the early 1980s. In Latin America, economic and financial instability stemming from debt problems have kept growth down. In Asia, low commodity prices have led to reduced acreage from the highs of the 1970s. In Africa, drought has severely limited agricultural production [WH87].

Fertilizer application rates have varied substantially across regions as well. The developed regions (North America and Western Europe) have mature agricultural industries, and fertilizer gains made through technological advances have been minimal since the early 1980s. Growth of fertilizer consumption has been strongest in those regions where fertilizer use has not matured, such as Latin America, Asia and Africa. Thus, while application rates are higher in the developed regions, growth rates of application per acre over time are much lower [WH88].

Differences in application rates by region also reflect variations in cropping patterns, soil quality and climatic conditions. Acreage shifts to coarse (or animal feed) grains in Western Europe have brought about an increase in the demand for fertilizer nutrients since coarse grains are fertilized more intensively than other crops [WH88]. In Latin America, fertilizer use has been among the lowest in the world due to high natural soil fertility. However, Latin America is the only region in the world where the application rate for phosphates is greater than that for nitrogen, due to differences in soil fertility and differing crop needs. According to Wharton Econometric Forecasting Associates (WEFA), the nitrogen-to-phosphate ratio in 1987 was 0.8 in Latin America, compared to 2.8 in North America, 1.2 in Africa, and 3.2 in Asia [WH88]. Hence, acreage shifts in Latin America have a relatively large impact in phosphate fertilizer consumption.

World demand for fertilizer has also been affected by shifts in crop prices. The general oversupply of farm commodities in Japan, Western Europe and North America in the early 1980s has changed the demand for plant nutrients. The Green Revolution in the 1960s introduced new, higher-yielding varieties of grains to the developing world, dramatically increasing yields and bringing many countries close to self-sufficiency in food. While the initial impact of the Green Revolution was to dramatically increase dependence on chemical fertilizers, by the early 1980s, it also enabled many countries to reduce their reliance on grain imports. By 1987, low world grain prices adversely affected acreage planted and fertilizer use in many grain-producing countries, particularly in the U.S. and Europe.

Domestic and export fertilizer prices have fluctuated very differently within different regions and countries. The reasons for these fluctuations are varied and include weather, government crop and fertilizer pricing policies, decisions to invest in new capacity, and capacity utilization. These elements have resulted in shortages and oversupplies of particular types of fertilizer at various times [WH87,WH88].

In general, however, over-investment in plant capacity relative to demand (both foreign and domestic) has led to lower fertilizer prices in all countries. Aggressive pricing policies by large suppliers such as Morocco have further increased the downward pressure on prices. In fact, by 1987 this situation had led a number of developed countries (European Economic Community, U.S. and Australia) to impose minimum prices, quotas and/or dumping margins on fertilizer imports. Regulatory agencies in these countries found that LDC imports had been sold below their fair market value and had caused material damage to domestic suppliers. These trade restrictions generally resulted in higher domestic prices in these countries [Co87].

Finally, demand for fertilizer depends on the availability of foreign exchange, particularly for LDCs. Oil price increases in the 1970s, while causing balance-of-payments problems, also directed more money to Western bankers who were then willing to increase loan portfolios in LDCs. LDCs used the increased availability of foreign exchange to buy farm supplies and inputs, pushing up the demand for fertilizer in the 1970s and early 1980s. This situation lasted until rising interest rates in the 1980s, low commodity prices, and ensuing Third World debt service problems restricted the availability of foreign exchange in LDCs. Thus, despite drops in fertilizer prices in the 1980s, many less-developed economies were unable to import their full requirements. In the 1980s, aid and concessionary loans have played an important role in determining fertilizer imports and use.

9.2.2.3 World Demand for U.S. Phosphate Exports

World Trade Characteristics

World exports of the three plant nutrients, nitrogen, phosphorus and potassium, presently amount to approximately one-third of total world consumption, but this percentage has been declining. Most of the decline, particularly in phosphate trade, has been felt by the United States, since exports from African, Near East and Far East producers have actually increased.

In general, the share of the world phosphate trade held by the developed countries has been declining, though production from the developed economies still dominate world trade. The large increase in the LDC's share of world phosphate trade in the 1980s was largely due to the increase in Morocco's WPPA production capacity and the development of new plants in the Philippines. The Moroccan phosphate industry is government owned and has been pursuing an aggressive pricing policy aimed at increasing its share of the world market [Co87].

The regions most dependent on imports were Africa (which imports over 70 percent of its nutrient requirements, and about 58 percent of its phosphate needs), the Far East (which imports 40 percent on average, and 45 percent of its phosphate needs) and Latin America (importing 48 percent overall, and 55 percent of its phosphate requirements). In contrast, the developed countries imported on average 36 percent of their nutrient needs and 25 percent of their phosphate needs. Most trade by centrally planned economies was with other centrally planned economies [Co87].

U.S. Export Market

In recent years, U.S. phosphoric acid exports (which do not include phosphate fertilizers) have typically been less than 10 percent of total domestic output [St86a]. Exports, however, of phosphate fertilizers represent a much higher proportion of phosphate fertilizer production. The U.S. is the largest exporter of phosphate fertilizer to the world. But the U.S. share of the phosphate fertilizer export market has decreased from 53 percent in 1981-82 to about 47.6 percent in 1985-86. In 1987, according to The Fertilizer Institute, the U.S. exported 620,777 tons of merchant grade phosphoric acid, 2,686,104 tons of concentrated superphosphate and 6,564,300 tons of DAP. These export levels are a significant improvement over the levels reported by the Bureau of Census for 1985 and 1986 [Ye88,St86a]. Table 9-12 shows the level of the U.S. exports between 1979 and 1986.

U.S. exports have met increasing competition since the mid-1980s. Many phosphate rock producers in less developed countries have increased their capacity to convert phosphate rock into fertilizer. The resulting oversupply of phosphate commodities partially explains the soft and falling export prices of the late 1980s [St86a].

High tariffs on U.S. exports of phosphate rock and phosphate fertilizer also affect the demand for U.S. product. Domestic fertilizer companies paid about $200 million in tariffs in 1985. The Indian government alone collected $40 million from U.S. manufacturers. Such tariffs decrease the competitiveness of U.S. producers in the international market [St86a].

Nevertheless, foreign demand for U.S. phosphate fertilizer seems to have strengthened in 1987. Consumption of U.S. fertilizer by the rest of the world rose 2 percent in 1986/87 and 3 percent in 1987/88. Demand grew most rapidly in Asia and Latin America. Several major importers such as India and China have reduced their fertilizer reserves so that more of their demand is being reflected in increased imports than in preceding years [Te87].

The devaluation of the U.S. dollar in 1987 increased the competitiveness of U.S. producers with respect to foreign producers. Relaxed foreign exchange constraints in many LDC's have helped to increase U.S. exports to LDCs. Improved demand and reduced phosphate commodity stocks also helped push up phosphate fertilizer prices [Te87].

In addition, U.S. exporters have organized into a cartel-like operation to help promote their product more effectively abroad. In 1987, almost all U.S. exports were handled by The Phosphate Chemical Export Association (Phoschem), an association for the export of phosphate chemicals from the United States. Phoschem operates as a membership association under the provisions of the Webb-Pomerane Act of 1918 and is regulated by the Department of Commerce and the Department of Justice. The Act permits U.S. companies to effectively organize export operations in the face of overseas competition when this competition is considered to be, as U.S. manufacturers allege, in the form of a cartel. After nearly disbanding during the very soft 1985 export market, the organization has rebounded.

Trade in WPPA occurs at two levels. Of the $1.6 billion in phosphate fertilizer sales in 1985, 18 percent was in phosphoric acid and the remainder was in finished fertilizers, especially diammonium phosphate (DAP) [DOC86a]. The distribution of sales varies with each year. Large sales in recent years of phosphoric acid to the U.S.S.R. by Occidental Petroleum Co. and large sales of DAP to China have made the export market erratic. As described in the section on demand for phosphoric acid, in recent years competition has intensified in the markets for phosphate fertilizers and phosphoric acid.

Foreign Competition

Two types of foreign producers have cut into the U.S. export market. The first is new production in countries that have traditionally been important importers. The second is expanded production facilities in exporting countries. Importing countries such as The People's Republic of China and India have expanded fertilizer production capacities. Some of these facilities are not competitive with imports but are nevertheless protected from foreign competition. To a limited extent, these facilities have merely switched from importing finished fertilizers to importing phosphoric acid. Less developed countries are the primary competitors in the export market. Most of the LDC's new phosphate production capacity has been initiated by state owned enterprises. Other developed countries have production capacities that, with a few exceptions, cover only a portion their domestic needs. Western Europe has in recent years cut back production that supplied primarily domestic needs, in response to increased costs and environmental concerns.

Table 9-12: U.S. Exports of Phosphoric Acid
(Part 1 of 2)

(Thousand Metric Tons, Thousand Dollars)

	LESS THAN 65% P205		GREATER THAN 65% P205		TOTAL VALUE
	QUANTITY	VALUE	QUANTITY	VALUE	
1986	700	110,010	NA	NA	NA
1985	716	141,162	95	123,817	264,979
1984	867	181,055	854	215,513	396,568
1983	337	84,979	842	237,167	322,146
1982	530	117,785	893	289,296	301,291
1981	1,004	303,390	549	183,506	592,686
1980	1,212	281,348	84	21,686	303,034
1979	677	131,324	505	95,289	226,613

SOURCE: William Stowasser, Bureau of Mines, "Phosphate Rock," Minerals Yearbook, Preprint of 1986, 1985, 1984, 1982, 1980, 1978-79, 1977 and 1976. Also, Department of Commerce, U.S. Exports.

Table 9-12: Exports of Phosphate Fertilizer.
(Part 2 of 2)

(Thousand Metric Tons, Thousand Dollars)

	SUPERPHOSPHATE (1)		DIAMMONIUM		TOTAL FERTILIZER
	QUANTITY	VALUE	QUANTITY	VALUE	VALUE (2)
1986	1,237	155,861	4,120	641,385	907,256
1985	1,420	176,515	6,131	1,048,322	1,489,816
1984	1,092	149,150	6,346	1,200,579	1,746,297
1983	1,263	166,177	4,758	729,233	1,217,556
1982	1,148	158,140	3,707	678,685	1,138,116
1981	1,520	245,341	3,942	789,770	1,627,797
1980	1,577	287,366	4,995	1,095,944	1,686,344
1979	1,469	188,898	4,026	676,194	1,091,705
1978	1,494	145,703	3,929	525,610	671,313
1977	1,181	NA	2,581	335,883	446,417
1976	1,210	NA	2,182	269,855	380,690

1) The export figures for superphosphate are divided between fertilizer that is less than and greater than 40 percent phosphoric acid. These columns are summed above.

2) Includes pure phosphoric acid and other phosphate fertilizers besides superphosphate and diammonium.

In 1986, Monsanto Chemical Co. and FMC Corp. filed an anti-dumping petition with the U.S. Department of Commerce over imports of industrial phosphoric acid from Belgium and Israel[CMR86]. While this dispute does not directly affect the agricultural phosphoric acid market, it is an indication of the increased level of competition.

Table 9-13 shows the major exporting countries. The U.S. has maintained its dominant position in the phosphate fertilizer trade with over half of all sales. Morocco stands out as the key foreign competitor. Morocco is the leading exporter of phosphate rock and in recent years has dramatically expanded its phosphoric acid and fertilizer capacity. Moroccan phosphate fertilizer exports nearly doubled between the 1981/1982 season and the 1984/85 season and have continued to increase capacity. Phosphoric acid exports, which are more important to Morocco than are phosphate fertilizer, have also nearly doubled during this period [FAO85]. The Moroccan industry is operated by the state owned company, Office Cherifien des Phosphates (OCP). OCP has its own fleet of ships designed to transport phosphoric acid. Many in the industry believe OCP will operate at a loss in order to expand its market share and to bring in foreign currency.

Outlook

The predominance of domestically protected foreign production and state owned export competition has led Zellars-Williams to label the U.S. the "residual supplier." As world demand for phosphate product fluctuates, the production of U.S. firms goes up and down [Ze86]. This is because the U.S. firms are among the only ones that will not operate at a loss for prolonged periods. British Sulphur Corporation echoes Zellars-Williams' analysis and predicts that continued overcapacity in the international market will force the U.S. industry to consolidate to only 4 or 5 producers [BSC87b].

Since 1981, the U.S. has been unable to sustain the rate of growth of its phosphate exports. Zellars-Williams forecasts' that phosphate fertilizer exports from the U.S. will decline from 4.45 million tons in 1985 to 3.08 million tons in year 2005, while African exports will increase 1985 to 8 million in year 2005.[6] In Zellars-Williams' forecast, U.S. exports are fairly strong until the year 2000, when exports are projected to be at 5.3 million tons. However, between the year 2000 and 2005, U.S. exports plunge 42 percent. This decline coincides with the expected exhaustion of prime central Florida phosphate reserves and the need to develop new, more expensive reserves.

---

[6] Zellars-Williams' estimates of export differ from those given in Table 9-14, because this table reports exports on a "fertilizer year" (July 1 to June 30) instead of a calendar year.

Table 9-13: Trade in Phosphate Products by Major Exporter, 1981-1984 (1)

PHOSPHATE FERTILIZER
(METRIC TONS, P205)

	1981	1982	1983	1984
UNITED STATES	3,403,000	3,553,000	3,948,000	5,047,000
MOROCCO	125,542	207,308	383,315	245,500
USSR*	254,100	250,000	312,000	281,900
NETHERLANDS*	311,765	336,645	348,215	343,660
TUNISIA	445,600	454,564	485,300	441,280
CANADA	162,000	96,000	94,000	99,000
BELGIUM-LUX	470,000	411,000	480,000	450,000
TOTAL WORLD TRADE	6,450,486	7,064,137	8,213,908	9,193,717

*Large importer of phosphoric acid.

PHOSPHATE ROCK
(METRIC TONS, P205)

	1981	1982	1983	1984
UNITED STATES	10,554,000	9,735,000	13,197,000	11,318,000
MOROCCO	15,635,000	13,976,000	13,976,000	14,951,000
USSR	5,020,000	5,278,000	4,899,000	4,383,000
TOTAL WORLD TRADE	45,271,000	43,154,000	47,223,000	47,769,000

PHOSPHORIC ACID
(METRIC TONS P205)

	1981	1982	1983	1984
UNITED STATES	761,800	1,047,500	1,235,000	937,000
MOROCCO	548,900	649,800	857,700	1,080,800
TUNISIA	251,800	311,500	380,000	333,500
SOUTH AFRICA	229,600	228,100	123,300	211,900
TOTAL WORLD TRADE	2,453,200	2,880,500	3,189,500	3,258,700

1) Years indicated are "fertilizer years," from July 1 to June 30.
Source: Fertilizer Yearbook, Food and Agriculture Organization of the United Nations, 1985.

The decline in U.S. exports can be expected to continue as the less developed countries expand their phosphoric acid and fertilizer capacities. Zellars-Williams forecasts that the U.S. share of the phosphate rock export market will fall to 15.5 percent in the year 2005, from 23.1 percent in 1984. Zellars-Williams also forecasts that the Moroccan share of the export market will go from 31.4 percent in 1984 to 46.5 percent in 2005.

9.2.2.4 Demand Forecasts

There are a number of multi-equation models used for forecasting phosphate fertilizer demand. The models are of varying degrees of sophistication, use a variety of estimation methodologies and have differing time horizons. They all include, to one degree or another, the set of variables discussed in the preceding section; population, acreage of major crops harvested, fertilizer application rates, fertilizer and crop supply and prices, crop mix and yield estimates.

Forecasters disagree on the outlook for the world as a whole. The Food and Agriculture Organization (FAO) predicts that worldwide phosphate demand will grow less than one percent per year up to the end of the century. Zellars-Williams and WEFA analysts have a more optimistic outlook, estimating annual growth at 1.3 and 2.4 percent, respectively. Their optimism is based largely on the prediction that grain prices will increase due to grain stock depletion by 1995. While both sets of analysts expect North American phosphate demand to recover from its lows of the mid-1980s, neither expect acreage or production to increase to their early-1980 levels.

Table 9-14 provides a basis for comparison of the forecasts for four years of interest. The shorter-range forecasts provided by, or imputed from, the various models generally agree on the level of demand over the next few years. The more recent forecasts are substantially more conservative over the long run, reflecting new information about government-sponsored acreage reduction programs in the U.S. and Europe. For example, the 1979 Chase Econometrics forecast estimated that U.S. agricultural demand would grow 3 percent per year between 1979 and 2000, while the 1985 Bureau of Mines forecast implies a U.S. growth rate of 1.3 percent for 1983 through 2000. The earlier forecast also did not anticipate the drop in economic growth rates in LDCs and the emergence of Third World debt problems. The other forecasts provided in Table 9-14 were performed after 1983 and provide more pessimistic assessments due to these events.

However, all forecasters agree that phosphate fertilizer demand (and therefore demand for WPPA) in developed market economies will grow at a substantially lower rate than demand in other regions

Table 9-14

Summary Of World Phosphate Fertilizer Demand Forecasts

YEAR

(Million Nutrient Metric Tons P_2O_5)

Source	1990	2000	2010	2018
WEFA[1]	35.10	42.12	49.20	57.20
FAO[2]	37.35	47.67	59.68	72.66
BOM[3]	35.33	44.35	55.68	66.79
Chase[4]	36.31	48.80	65.58	83.07
Z-W[5]	41.75	50.48	59.58	70.36

Sources:

1) World Demand for Fertilizer Nutrients for Agriculture," Wharton Economic Forecasting Associates (WEFA), #OFR 24-88, Bureau of Mines, April 1988.

2) "Current World Fertilizer Sitation and Outlook, 1985/86-1991/92," Food and Agricultural Organization (FAO), United Nations, Rome, June 1987.

3) W.F. Stowasser, "Phosphate Rock," Minerals Facts and Problems, Bureau of Mines (BOM) Bulletin 675, 1985.

4) Study by Chase Econometrics, cited in "Phosphates," General Accounting Office (GAO), #80-21, November 1979.

5) Phosphate Rock 1985/86. Multiclient study by Zellars-Williams Co., Jacobs Engineering Group, 1987.

(see Table 9-15). The lower estimates reflect the fact that the developed market economies have more mature agricultural industries and thus potential fertilizer gains are minimal. In addition, new ideas for fertilizer application currently being implemented in these countries have resulted in reduced fertilizer requirements.

Forecasters agree that demand for fertilizer in Western Europe will be stable or decreasing over the next 20 years. These assessments are based on the maturation of the agriculture industry in these countries, and more specifically on the expectation that Western European governments will implement programs to reduce agricultural subsidies and stimulate a decline in crop acreage. On the other hand, WEFA analysts note that a possible future shift from food grain to feed grain production will stimulate phosphate fertilizer use [WH88].

Analysts at Zellars-Williams estimate that population pressures and the pursuit of food self-sufficiency policies in Asia will keep demand for phosphate fertilizers in that region growing at an annual rate of about 3.4 percent at least until the year 2005. WEFA analysts estimate a lower 2.7 percent growth rate for the same time period. Their lower growth estimate reflects beliefs concerning fertilizer use in Asia. WEFA analysts believe that Asian countries will experience diminishing returns to fertilizer applications by 1995, leading to reduced fertilizer requirements in that region [WH88].

Most of the future demand for phosphate fertilizers in Africa will result from increased application rates rather than increased acreage. Climatic conditions and destructive farming practices are likely to continue to turn much African land into desert. WEFA projects that acreage in the region will grow less than one percent per year [WH88].

All forecasters seem to agree that Latin America has tremendous potential for growth in agriculture and fertilizer usage over the next 25 years. This optimistic assessment is based on the fact that certain countries in the region are the lowest-cost producers of corn, soybeans and wheat, and hence will be producing increasing shares of these major crops in the future. In addition, analysts expect agriculture in the region to become more intensive. Agricultural policy will seek to meet production targets by increasing yields rather than opening new lands for cultivation.

Thus, in general, most of the growth in demand will come from LDCs in Asia and Latin America. Within Asia, most of the growth is expected to come from the People's Republic of China; in Latin America, most of the growth is expected to come from Brazil and Mexico, although the debt and

Table 9-15: Forecasts of Fertilizer Demand by Region and Source, 1995-2005

(Million Metric Tons P205)

	1995			2000			2005		2010
REGION	WEFA	ZW	FAO	WEFA	ZW	FAO (1)	WEFA	ZW	WEFA
NORTH AMERICA	5.0	5.6	4.2	5.6	5.9	5.3	6.2	6.2	6.8
LATIN AMERICA	2.8	3.1	3.3	3.2	3.6	2.6	3.5	3.8	3.9
WESTERN EUROPE	4.9	6.6	5.2	4.9	7.0		4.8	7.5	4.8
AFRICA	3.6	3.5	0.8	1.5	2.3	0.5	1.6	2.5	1.7
ASIA	11.4	14.2	10.8	13.0	15.7	15.1	14.5	16.7	16.0
CHINA		6.8	3.4		7.8	12.0		8.3	
OCEANIA	1.0	1.3	1.2	1.1	1.3	0.4	1.1	1.3	1.2
CENTRALLY PLANNED ECONOMY	12.0	12.2	11.4			1.8	13.9	15.7	14.9
E. EUROPE	3.6	3.5		3.9	3.6		4.2	4.6	4.4
USSR	8.3	8.7		9.0	10.1		9.7	11.1	10.5

(1) Refers to 1997/98 (only).

Sources: "World Demand for Fertilizer Nutrients for Agriculture," WEFA, #OFR-24-88, for Bureau of Mines, April 1988; Phosphate Rock 1985/86, Zellars-Williams, 1987; "Current World Fertilizer Situation and Outlook," Food and Agriculture Organization of the United Nations, June 1987.

foreign exchange problems of both countries are expected to dampen import consumption and encourage further investment in domestic capacity.

Most of the forecasts mentioned do not deal directly with U.S. exports. Zellars-Williams, however, expects U.S. exports to increase until 1990 and to fall by almost 50 percent between 1990 and the year 2005 [Ze86]. This reflects the expectation that an increasing share of WPPA will be supplied by LDCs. WEFA expects an average growth in exports of 2.0 percent per year until 1996 [WH88]. Phosphate exports, according to the WEFA analysis, will constitute over half of the total identified demand for U.S. produced phosphates over the forecast period. Thus, the outlook for the domestic phosphate industry is unclear.

9.2.3 Other Issues

9.2.3.1 Substitutes

Besides phosphate ore, guano (igneous apatite and marine phosphorites) is the only significant source of phosphorus. However, it is no real substitute for phosphate rock as a raw material for producing phosphate fertilizers. Guano accounts for about 3 percent of world production of phosphate. All large accumulations of guano were formed on the surface of the earth by seabirds. The composition of these deposits varies with the degree of leaching by surface waters. Chile holds most of the world guano supply [St85].

In some limited cases, phosphate rock can be used directly as a fertilizer, instead of first being converted into phosphoric acid. According to Ed Harre at the National Fertilizer Development Center, approximately a million tons of phosphate rock is used in this way each year around the world, mostly in the Soviet Union. The rock must be finely ground and even then only a small percent of the P_2O_5 can be absorbed by the crops. The yield response is best in very acidic soils.

A potential substitute for the production of phosphoric acid is the production of nitrophosphate (NP) fertilizers. In this process, nitric acid is substituted for sulfuric acid. NP is produced in Europe, India and China but not in the U.S. One study estimates that sulfur prices would have to double, to $200 per ton for the process to become economically attractive. In any case, environmental concerns remain with NP. With NP, the radium in the phosphate rock is absorbed into the fertilizer instead of remaining in the waste product [Pl87,Pl88]. Consequently, the radon emissions from the spreading of the radium over millions of acres of farmland would certainly exceed the emissions from phosphogypsum stacks.

Spent acid from aluminum bright dipping is a substitute for WPPA in the manufacture of ammonium phosphates only. The spent acid is recovered from aluminum bright-dip baths and may be used in the production of fluid mixed fertilizers. This product is being used for this purpose in the midwest and southeast, where most bright-dip plants are located. Its price per unit of P_2O_5 is usually lower than the price for WPPA. But the availability of this spent acid has been declining in recent years as large U.S. bright-dipped aluminum alloy manufacturers have installed acid regeneration units in their plants. Increased regeneration activity has been concurrent with the decision of auto manufacturers to use less bright-dip trim on cars [SRI86].

Thermal phosphoric acid is also a substitute, but its production costs are much higher and the production of thermal phosphoric acid presents other environmental problems.

9.2.3.2 Alternative Uses for Phosphogypsum

Alternative uses for phosphogypsum attempt to exploit the material's two key properties: its physical similarity to natural gypsum, and its sulfur and calcium content. Industrial and agricultural uses for phosphogypsum are nothing new: research into sulfuric acid production from phosphogypsum started at least as early as World War I [BSC85g]. Applications in building materials were common in Europe until the 1950s and in the U.K. until the 1970s [BSC87f] and are still found in Asia [FIP88]. Below is a review of the current uses of phosphogypsum and of the limited data available on radiation levels from these uses.

Current Uses -- Alternative uses in the United States are fairly recent phenomena, and are a small scale; one industry source estimates that only about 5 percent of U.S. phosphogypsum output is put to use in some way [An88]. The end of this section summarizes the information available on uses of phosphogypsum by U.S. companies. By contrast, a 1981 study by a United Nations researcher estimated that 14 percent of world phosphogypsum output was reprocessed [Ca88].

Most of the research in the U.S. has focused on two uses: the use of phosphogypsum as a road base, usually mixed with other material, and processing of phosphogypsum into sulfuric acid and aggregate, a solid material that can be used for a variety of construction purposes. Agricultural applications, more common overseas, have been somewhat limited in the United States. Other uses for phosphogypsum have been tried on a small scale but never widely adopted.

Building Materials -- Much effort has been devoted to the development of methods which use phosphogypsum as a construction material. Many of these are the same as uses for natural gypsum; for example, plaster and wallboard. The use of phosphogypsum in building materials is hence doubly attractive where natural gypsum is expensive or impossible to obtain locally and disposal of phosphogypsum poses economic or environmental problems. For example, in Japan, where there are no natural deposits of gypsum and land for dumping is scarce, the Nissan company has developed and installed its own advanced phosphoric acid production technology to produce high-quality byproduct gypsum.

There is no evidence that phosphogypsum straight from a stack is suitable for use in construction materials. The phosphogypsum must be produced in a purer form than is usual in the U.S., and then dried, or processed. It is then combined with some other substance (often flyash) and compacted to make bricks, blocks or boards, or molded into plaster. Laboratory tests at the University of Miami found that, depending on moisture content, compacted phosphogypsum can achieve compressive strength as high as 1000 pounds or more per square inch [Ch87]. Phosphoric acid plants in Austria, Japan, and Belgium have been designed to produce as a byproduct high-quality phosphogypsum specifically for construction purposes [Ca88]. Construction uses in Europe have become more common as restrictions on dumping at sea have been imposed; at least one German firm sells wallboard and other construction materials fashioned from phosphogypsum [Ll85]. The Donau Chemie Company in Austria has one 50,000 ton per year phosphoric acid plant where all of the byproduct phosphogypsum is recycled into building materials [Ca88]. A technique for purifying phosphogypsum to make it suitable for building materials has been patented by the American company United States Gypsum but has never seen commercial usage [Mn88]. There is no evidence that phosphogypsum has found a building materials market in America.

Road Base -- Phosphogypsum is well-suited for use as a road bed. Either the aggregate from a cement and acid process or unprocessed waste gypsum may be used. Unprocessed phosphogypsum for use in road beds, mixed with flyash, cement, or other materials, has found an increasing but limited market in America. Since July 1984, Mobil Mining and Minerals in Pasadena, Texas has taken phosphogypsum from inactive stacks, mixed it with 6 percent cement, and sold it as "Gypsum Aggregate." As of December 1986, over 300 projects utilizing a total of 340,000 tons of Mobil phosphogypsum had been completed [FIP88]. Mobil's Gypsum Aggregate has a number of other uses, including railroad base and embankment construction. However, despite the good engineering qualities of gypsum from phosphogypsum in this use, it is profitable to produce and sell as a road base only where there is no natural local source for aggregate material because of high transportation costs. Some of Mobil's success in this area is because the Houston area has few sources of aggregate.

In Florida, some unknown number of private roads and parking lots have a phosphogypsum base; but since they were built informally, little is known about the details of their construction [LI85].

Circular Grate Technology -- The alternative use which has received the most attention in recent years and which holds the most promise for the future concerns the processing of phosphogypsum to produce sulfuric acid and a solid material, called aggregate. There are a number of techniques of this type, generically referred to as "cement-acid processes." The most discussed technique for this is known as the "circular grate process." The process can be varied to produce various forms of aggregate appropriate for different applications [Ke86]. As mentioned, the production of sulfuric acid from phosphogypsum dates back at least 50 years, but the high energy costs of earlier techniques rendered them economically infeasible under most conditions. However, some recent studies indicate that use of the circular grate process can lead to rates of return as high as 25 to 38 percent [Mc87c]. A pilot project at Freeport McMoRan's Uncle Sam plant in Louisiana, co-sponsored by the Florida Institute of Phosphate Research and the Davy McKee Corporation, is expected to use 35 tons of phosphogypsum and other inputs each day and produce 29 tons of sulfuric acid and 25 tons of aggregate per day when it begins operation which is expected to be in early September of 1988 [Mc87c,LL88].

Where there is no nearby cement supply, other technologies can be profitable; for example, the Fedmis Division of Sentrachem Ltd. in South Africa operates a 70,000 ton per year cement and acid plant. Forty percent of Fedmis phosphogypsum output goes into profitable recycling. The Fedmis example is unusual because reasonably priced cement is not available in the region surrounding the Fedmis plant. Cement produced elsewhere and shipped to the area is not competitive because of the high relative cost of transporting cement.

Strong demand for aggregate in Florida is expected to last for several decades, as the state's population is forecast to increase to over 15 million by the year 2000 [DOC88c]. With higher population there will be a need for more roads. Most of the aggregate used to build roads in Florida has to be brought in from outside the state; since many phosphate producers are located there, there are some hopes in the phosphate industry that both the road and phosphogypsum problems may be solved at once, using the circular grate technology [BSC87g]. However, some sources in companies not directly involved in the circular grate process are skeptical about this new technology. Several people in the industry argue that low sulfur prices and high transportation costs for aggregate make the technology unprofitable. Others doubt that it is technically feasible. However, it is estimated that the circular grate process could produce sulfuric acid at a cost of $21.65 per short ton, compared to $43.70 per short ton for the more traditional sulfur burning process [BSC87h]. Iowa State

University has developed a similar process using a fluid bed reactor rather than a circular grate, but this approach has never left the test-plant stage [Mn88].

Agriculture -- Phosphogypsum also has properties which make it potentially useful in agriculture. As a fertilizer, it contains significant amounts of sulfur and calcium, both beneficial to growing plants. According to Mike Lloyd of the Florida Institute for Phosphate Research, the sulfur content is in a form usable by the soil directly, without any processing of the phosphogypsum. Of 18 American companies for which information is available, 8 currently sell some amount of phosphogypsum for agricultural use; 3 have done so in the past but have stopped recently, usually because the sales proved unprofitable. However, in all cases these sales have been small compared to total phosphogypsum output, occasionally as much as 5 percent but often less than 1 percent of total phosphogypsum produced by the firm. Application rates have been estimated as varying between one half and 3 tons per acre, depending on locale and crop [Mc88].

There are two reasons why phosphogypsum is not used more for agricultural purposes. First, only a limited number of crops benefit from phosphogypsum. Second, the potential profits from the phosphogypsum are small relative to its bulk. Consequently, even at little or no cost for the material, it is not profitable to transport phosphogypsum for long distances.

In other countries, phosphogypsum is used as a fertilizer. In India, the Gujarat State Fertilizer Company has been making high-quality gypsum from phosphogypsum and also converting it into ammonium sulfate fertilizer at a facility with 205-210 metric tons per day capacity [FIP88]. As a soil additive, it can be used to remove aluminum toxicity [Ll88]. It is also used to make clay and other tough soils more porous, improving drainage [FIP88].

Sulfur Recovery -- As the price of sulfur has risen, more research has focused on potential methods of recovering the sulfur from phosphogypsum. A significant proportion of the energy and capital costs in the acid-cement techniques goes into producing commercial-quality cement. This fact has led at least one source to comment that the use of these techniques should be considered as cement production rather than acid production [FIP88]. Elemental sulfur can be produced via thermal processing of gypsum (natural or byproduct). Due to energy and capital costs, this technique has been feasible only when the supply of sulfur is extremely limited--for example, it has been used abroad when wartime blockades or government import controls have cut sulphur supplies [Ll85]. The British Sulphur Corporation has speculated that environmental considerations may lead to more thermal processing of waste gypsum to yield elemental sulfur, even when it is not "strictly profitable [BSC87g]."

Radiation Considerations -- A few studies of radon and radioactivity hazards in alternative uses of phosphogypsum have been completed. One University of Florida study of agricultural applications estimated the radionuclide uptake by plants, the resultant concentration in food, and the subsequent doses to consumers, for applications of one ton of phosphogypsum per acre every four years. The study claimed to find no significant radiological problems implied for horizons of up to 50 years [FIP88].

University of Miami engineering professor Wen F. Chang claims that radon emissions from phosphogypsum are greatly reduced when it is compacted (to make bricks, for example). He estimates that emissions can be reduced 80 to 95 percent compared to the powder form, depending on the force of compression [Ch88].

Two experiments have measured radon concentration in enclosed rooms fashioned from phosphogypsum panels [FIP88]. The first study was conducted by researchers from the University of Miami and Jacobs Engineering, the second by a University of Miami professor. In each study, the 'worst case' was examined: the rooms were windowless and ventless and constructed entirely from the wallboard. In addition, the wallboard was painted on the outside of the room to minimize the escape of radon gas. In both cases, radon concentration in the structure approached or was as high as (EPA or Florida state) screening levels. In addition, the former study measured radon emissions when the panels were painted on the surface facing the inside of the room and found that emissions were reduced by 95 percent. Wen F. Chang, the University of Miami professor who performed the second experiment, claims that painting the phosphogypsum panels reduces emissions to negligible levels, and that the materials he has produced experimentally will pass any building code [Ch88].

Little data on radon emissions in roadbase use is currently available, although a University of Miami study has examined the impact of a phosphogypsum roadbase in Polk County, Florida on local groundwater quality [FIP88]. Neil Anderson, venture manager of the phosphogypsum project at Mobil Mining and Minerals, claims that radon emissions from an installed phosphogypsum roadbase of Mobil Gypsum Aggregate (without an intact covering such as asphalt) are 1 to 2 picoCuries per square meter per second, and when the roadbase has an intact covering the emissions are essentially none [An88]. However, such coverings almost always develop cracks which allow disproportionate amounts of gas to escape. Mr. Anderson states that a hydration reaction takes place when the phosphogypsum is mixed with cement, reducing the radon emissions. The following section summarizes alternative uses of phosphogypsum by various companies.

Specific Uses Of Phosphogypsum by U.S. Companies

Allied -- A small amount of phosphogypsum is sold from a plant in Geismar, Louisiana for agricultural use on sugarcane. The volume sold is far less than one percent of output, estimated at 5000 tons out of a total production of 750,000 tons per year. The farmers are not charged for the material itself, only for loading. Demand for phosphogypsum is erratic.

C F Industries -- The company previously sold phosphogypsum from its Florida operations to peanut farms in Georgia, but has not sold any since its plant shut down about five years ago.

Farmland -- Farmland operates wet-process phosphoric acid facilities in southern Florida. Some amounts are shipped for agricultural use, estimated to involve 0.2 percent or less of annual output, between 0 and 5000 tons per year. It is generally used as a sulfur source on peanut fields in Georgia.

Four Court Incorporated -- Eight million tons are stockpiled in the Utah plant which the company bought from Chevron. Each year, 200,000 tons are shipped to the San Joaquin Valley in California for use as a soil conditioner for sodic soils. According to Ed Sepehrenik, FCI engineer, California demands a total of 750,000 tons per year from various sources. There is also some agricultural use in Montana. A process which Mr. Sepehrenik designed himself and which is still in the experimental stage produces sulfuric acid and an animal feed supplement; the latter can be sold for $450 per ton.

Gardinier -- Gardinier operates one wet-process phosphoric acid plant, in Tampa, Florida. The company had some agricultural sales of phosphogypsum in previous years, although not recently since it is not profitable to sell. Gardinier has stockpiled phosphogypsum at rates up to 4 million tons per year for the last 50 years.

Mobil Mining and Minerals -- Mobil operates a wet-process phosphoric acid plant in Pasadena, Texas. The company previously sold phosphogypsum off the stack for agricultural use, and is currently waiting for its license permitting this practice to be renewed by the Texas State Health Department. The phosphogypsum was used as fertilizer for its calcium and sulfur and to condition sodic soils. Mobil currently sells about 10-15 percent of its phosphogypsum output and hopes to sell more in the future. As described above, Mobil also has been aggressive in developing a road building market for phosphogypsum.

Occidental -- The company owns one WPPA facility, in White Springs, Florida. Occidental sells about 100,000 tons a year of straight phosphogypsum for agricultural use, less than 1 percent of total output. Markets are Georgia, Alabama, North Carolina, South Carolina, Texas, and Virginia. Peanut farmers are most interested since phosphogypsum is especially suited for that crop.

Royster -- Very little of its phosphogypsum goes to agricultural uses, less than 1 percent.

Simplot -- The company has closed 2 plants in California, one in 1982, the other more recently. The last of the phosphogypsum from those plants was shipped out recently. It had previously sold about 300,000 tons per year from plants in California. Its Pocatello, Idaho, plant currently sells much less, about 40,000 to 50,000 tons per year, 3 to 4 percent of output. In Idaho, phosphogypsum is typically used on alfalfa, onions, and potatoes; the usual application rate is about one half ton per acre. In California, it is used on irrigated field crops, cotton, grain, wheat, beets, and alfalfa, with an application rate of about 1 to 3 tons per acre. The only processing of phosphogypsum undertaken is 'diking' to bring moisture to around 12 percent. Price runs about 12 dollars per ton loaded onto trucks, and as much as 35 dollars per ton delivered to farm. According to Jim McGinnis, Distribution Manager, use in Idaho will probably increase a little; it is expected that some may be shipped to California.

Texasgulf -- The company operates one WPPA plant in Lee Creek, North Carolina. About 100,000 to 150,000 tons of phosphogypsum per year is used as peanut fertilizer in North Carolina and Virginia, from a total of 5 to 6 million tons of phosphogypsum produced per year; phosphogypsum is also blended with clay separated from phosphate rock and used to reclaim mine land. The company's ultimate goal is to return all its phosphogypsum to the land in this way.

9.3 Current Emissions, Risk Levels and Feasible Control Methods

9.3.1 Introduction

The phosphate fertilizer industry described in section 9.2 is the subject of possible environmental controls. These controls would reduce the incidence of lung cancer attributable to radon emissions from the phosphogypsum stacks associated with the production of P_2O_5. One or more of these stacks are located at most P_2O_5 production facilities. Nationally, fifty-eight stacks have been identified. The analyses in this and the following sections of this chapter (9.4 through 9.6) consider the costs, magnitudes and effects on the risks of lung cancer of radon emission reductions, their benefits in relation to their costs, their effects on economic activity in the United States and on the well-being of small entities.

Because the parameters affecting the radon emissions from all these stacks are not available and because economic data is available for P_2O_5 producers linked to only a subset of the stacks, detailed economic analysis is done for fourteen of the fifty-eight stacks. Details of the selection of the fourteen appear in section 9.5.

9.3.2 Physical Attributes of Phosphogypsum Stacks

9.3.2.1 Design and Construction

Phosphogypsum is created when phosphate rock and sulfuric acid are combined to produce P_2O_5. The amount of phosphogypsum produced is approximately five times that of the P_2O_5 produced. For disposal, the phosphogypsum is carried by a slurry and deposited on large piles known as stacks.

The stacks are large. Their bases range from 2 hectares to 284 hectares and some currently reach a height of 50 meters. The quantity of phosphogypsum deposited in a stack in a year may reach 1,550,000 metric tons.

While the stacks are irregular in shape, they roughly resemble a rectangular box, with sloping sides. While the sides of most stacks are sloped with one vertical meter for every three horizontal meter, stacks in Louisiana and Mississippi have a more gradual slope, about one in eight. (Table 9-16) For the purpose of modeling, it is also assumed that the length of the base of a stack is twice its width.

The tops of the stacks are constantly changing as a slurry of phosphogypsum is deposited first on one segment, and then on another, of the tops. A road around the top and dikes to contain the new deposits of phosphogypsum are frequently rebuilt to accommodate the changing dimensions of the sides and top. When one section of the top is filled, it is allowed to dry and the flow of slurry is diverted to another section. Much of the top is under water at any time, not only while the slurry is settling, but also because portions of the tops are used for water storage as part of the waste water management plan for the production facility.

9.3.2.2. Radon Emissions from Uncontrolled Stacks

Radon emissions from uncontrolled stacks depend on the flux, or rate of release of radon from the phosphogypsum in the various portions of a stack, and on the areas of these portions. Radon flux from the sides differs from the fluxes from the top. On top, the portions that are under water have

Table 9-16: Stack Parameters

	STACK #	HEIGHT (meters)	BASE AREA (hectares)	SLOPE (1/entry)	CAPACITY (1000 MT/yr)	REGION	STATUS
	1	10	9	3		3	Inactive
	2	24	18	3	115	3	Open
	3	18	20	3	430	3	Idle
	4	18	30	3	115	3	Open
*	5	27	31	3	90	3	Open
*	6	10	32	3	90	3	Open
	7	20	40	3	340	3	Open
	8	22	40	3	340	3	Open
	9	9	40	3	0	3	Idle
	10	9	50	3	0	3	Idle
*	11	18	53	3	340	2	Open
	12	23	61	3	430	3	Open
	13	6	64	3	140	3	Open
*	14	20	92	3	520	3	Open
	15	21	121	3	170	3	Open
	16	54	138	3	650	3	Open
	17	40	146	3	630	3	Open
*	18	21	140	3	380	3	Open
*	19	28	162	3	760	3	Open
	20	12	164	3	140	3	Open
*	21	24	157	3	1550	3	Open
*	22	12	17	3	320	1	Idle
	23	24	36	3	280	1	Open
	24	18	81	3	320	1	Open
	25	9	7	3		3	Idle
	26	5	10	3	110	3	Idle
	27	18	10	3		3	Idle
	28	9	18	3		3	Inactive
	29	4	28	3		3	Inactive
	30	16	32	3		3	Idle
*	31	13	40	3	110	3	Open
	32	27	77	3	110	3	Open
	33	9	20	3		3	Idle
	34	30	20	3		3	Idle
	35	5	24	3		3	Idle
*	36	4	9	5	420	3	Open
	37	10	9	5	160	3	Open
	38	14	11	5	0	3	Idle
	39	27	14	5	0	3	Idle
	40	27	38	3	0	3	Idle
	41	12	203	8	420	3	Open
*	42	20	284	8	800	3	Open
	43	20	101	10	220	3	Open
	44	10	0	3		3	Idle
	45	10	20	3		3	Idle
	46	15	28	3		3	Idle
	47	10	20	3	383	2	Open
	48	10	29	3	383	2	Open
	49	10	97	3	383	2	Open
	50	3	2	3		3	Idle
	51	11	11	3		3	Inactive
	52	11	14	3		3	Idle
	53	27	14	3		3	Idle
*	54	27	24	3	220	3	Inactive
*	55	27	36	3	220	3	Idle
*	56	30	61	3	220	3	Open
	57	5	121	3	90	1	Open
	58	10	182	3	180	1	Open

* -- Fourteen representative stacks selected for further study.

no flux while the dry portions and the roads have differing fluxes. Since roads, dikes, and underwater portions of the top are in relatively constant ratios to each other as the stack grows, weighted averages of the fluxes on the top can be computed for each geographical region. This is the value used in computations of total radon emissions from the tops of the stacks. Radon emissions for a stack equal the sum of the products of its top and sides and its flux rates.

Radon flux also depends on the composition of the phosphate rock that went into the P_2O_5 production and on the rainfall of the region. Flux rates were developed for three regions of the nation. Region one contains Idaho, Utah, and Wyoming; region two is North Carolina and northern Florida; and region three is the rest of the United States. (Table 9-17)

Calculations of radon emissions from each stack considered were done using a computer model that first computes the areas of the sides and top of each stack, and then its radon emissions as it grows, and areas and emissions of each stack after they reach their full sizes and are closed. Table 9-18 shows the total, uncontrolled, current emissions for each stack as calculated by the model.

9.3.2.3 Risks Due to Uncontrolled Stacks

The emissions shown in Table 9-18 result in some risk of lung cancer to the population. Two kinds of risk were considered, risk to the individual most exposed to each stack and risk to the population within an 80 km radius of each stack. These risks were calculated for each stack individually based on its emissions by running the AIRDOS-EPA computer code. The results of these runs for the fourteen stacks are also shown in Table 9-18.

9.3.3 Feasible Control Methods

9.3.3.1 Description of Controls

The primary control technique considered for the reduction of radon emissions from phosphogypsum stacks is to cover the stacks with a layer of dirt. To meet a given standard a sufficient thickness of dirt must be used. The thickness of dirt needed depends on the desired standard, the radon flux rate from the stack, and the properties of the dirt used. The major option available is whether to add dirt on the sides while the stack is in operation or wait until it is closed. The top can only be covered after the stack is closed.

Table 9-17: Radon Flux
Rates by Regional Group
(pCi/m2/s)

GROUP 1
Idaho, Utah, Wyoming

	flux from:	
	TOP	SIDES
while		
OPERATING	4.5	14.0
CLOSED	7.3	9.5

GROUP 2
North Carolina and Northern Florida

	flux from:	
	TOP	SIDES
while		
OPERATING	1.5	3.0
CLOSED	1.0	2.0

GROUP 3
All other states

	flux from:	
	TOP	SIDES
while		
OPERATING	4.0	9.0
CLOSED	4.0	12.0

Table 9-18: Incremental Cancer Risks Associated with Exposure to Radon Emitted from Phosphogysum Stacks with No Controls

STACK #	STACK # FROM TABLE 9-16	STATE	RN-222 EMISSIONS (Ci/yr)	MAXIMUM LIFETIME FATAL CANCER RISK	COMMITTED FATAL CANCERS/YR (0-80 km)
1	5	Florida	61	1E-05	6E-03
2	6	Florida	50	1E-05	7E-03
3	11	Florida	20	5E-06	1E-03
4	14	Florida	150	4E-05	1E-02
5	18	Florida	218	1E-05	2E-02
6	19	Florida	263	6E-05	3E-02
7	21	Florida	279	2E-05	3E-02
8	22	Idaho	39	9E-06	9E-04
9	31	Illinois	64	4E-05	3E-03
10	36	Louisiana	16	1E-06	9E-04
11	42	Louisiana	486	7E-05	3E-02
12	54	Texas	47	7E-05	9E-02
13	55	Texas	67	8E-05	1E-01
14	56	Texas	113	9E-05	1E-01

The computer model used to analyze the control alternatives provides three scenarios. Scenario 1 is to cover the sides while the stack is in operation and the top when it is closed, scenario 2 is to cover the sides and top when the stack is closed, and scenario 3 is to do nothing. The model also allows flux standards to be set at any level. These levels are considered: 20 pCi/m^2/sec, 6 pCi/m^2/sec, and 2 pCi/m^2/sec.

Since all stacks already have radon fluxes of less than 20 pCi/m^2/sec, only the latter two fluxes were analyzed. The model calculates a thickness of dirt based on the highest flux rate from any portion (top or sides) of the stack at any time. Runs were made for the following four combinations:

1. flux standard = 6 pCi/m^2/sec and scenario = 1
2. flux standard = 6 pCi/m^2/sec and scenario = 2
3. flux standard = 2 pCi/m^2/sec and scenario = 1
4. flux standard = 2 pCi/m^2/sec and scenario = 2

In the model, the ratio of the covered to uncovered flux (R) is computed for each stack and flux standard. Thickness is then found from equation (1).

(1) $R = \exp(-B * \text{thickness})$
where
B is a property of the soil cover, and
R is the ratio of controlled flux to uncontrolled flux

Table 9-19 shows the ratios and thicknesses of dirt for flux standards of 6 pCi/m^2/sec and 2pCi/m^2/sec The thickness of dirt applied to most portions of each stack in each situation is greater than is needed to meet the flux standard. The exact emission change resulting from the actual amount of dirt applied is calculated. These emission reductions are greater than required to meet the stated standard. However, the convenience of applying a uniform thickness of dirt to an entire stack was considered to offset the savings of adjusting the amount of dirt used on each portion of the stack in each situation. In particular, it was not contemplated that dirt would be removed from the sides of a stack after it was closed in cases where the sides of a closed stack have a lower radon flux rate than those of an open stack.

To cover the stacks, various preparations must be made and specific steps followed. First drains must be laid on the stack. The drains prevent acidic water from seeping from the stack and killing the ground cover. Vertical drains are installed every 30 meters around the base and slant upward to a spacing at the top proportional to the spacing at the bottom. A peripheral drain is installed every ten

Table 9-19: Control Parameters for Representative Stacks

STACK #	STACK # FROM TABLE 9-16	STATE	"B"	STD=6		STD=2	
				RATIO	THICKNESS	RATIO	THICKNESS
1	5	Florida	1.80	0.400	0.51	0.133	1.12
2	6	Florida	1.80	0.400	0.51	0.133	1.12
3	11	Florida	1.80	0.400	0.51	0.133	1.12
4	14	Florida	1.70	0.401	0.54	0.133	1.19
5	18	Florida	1.80	0.400	0.51	0.133	1.12
6	19	Florida	1.70	0.401	0.54	0.133	1.19
7	21	Florida	1.70	0.401	0.54	0.133	1.19
8	22	Idaho	0.83	0.429	1.02	0.143	2.34
9	31	Illinois	1.30	0.400	0.71	0.133	1.55
10	36	Louisiana	2.30	0.400	0.40	0.133	0.88
11	42	Louisiana	2.20	0.400	0.42	0.133	0.92
12	54	Texas	1.70	0.401	0.54	0.133	1.19
13	55	Texas	1.70	0.401	0.54	0.133	1.19
14	56	Texas	1.70	0.401	0.54	0.133	1.19

Where:

RATIO = the ratio of radon flux (pC/m^2-sec) from a covered surface to that from an uncovered surface and is given by:

$$R = \exp(-BX).$$

THICKNESS = soil thickness on the stack (given above in meters).
B = an empirically estimated coefficient that is a function of soil moisture content (described in the text of this report).
STD=6 = the flux standard that allows 6 pCi/m^2-sec.
STD=2 = the flux standard that allows 2 pCi/m^2-sec.

meters of vertical height and connected to the vertical drains. If the entire stack is covered at closure, as in scenario two, then all drains are installed simultaneously. But if the stack is covered during operation, then vertical drains are installed continuously as the stack progresses and peripheral drains are installed each time the stack grows ten meters in height.

Once the drains are in place, dirt is hauled to the site, placed on the stack, graded and compacted. The dirt is then seeded with grass. The grass and drains require annual maintenance. Dirt is assumed to be added every time the stack grows 3 meters in height. Before the top is covered, a synthetic cover is placed over it. Then dirt is hauled, placed, graded and compacted over the cover and grass is planted and maintained. No drains are installed on the top.

If the regulations required scenario one, covering the sides as the stack grows, existing stacks would have to install drains, cover their sides and plant grass right away. The program closes operating stacks when their tops get too small to accommodate more slurry. The minimum size needed for the top depends on the level of activity. If a large amount of P_2O_5 is being produced, a large top is needed. The stack is closed when the area of the top in square meters is less than .32 times the amount of P_2O_5 produced per year measured in metric tons.

9.3.3.2 Costs of Controls

Costs of controlling radon emissions were computed by the Basic model for each of the fourteen stacks and for each of the four combinations of flux standards and scenarios. In computing the costs, the following cost items were included from the Appendix to Volume 2:

ITEM	COST	
dirt costs	$22.56	per cubic meter
purchase price of dirt		
haulage costs of dirt		
grading and placement of dirt		
seeding costs	$0.62	per square meter
peripheral drains	$27.62	per meter
downspouts	$27.62	per meter
maintenance	$0.29	per square meter
synthetic cover for top	$1.70	per square meter

The distribution of costs over time depends on the scenario. For scenario one, the initial year includes expenditures for installing downspouts, dirt and grass on the existing sides. If the stack has reached significant height, the first year's activities are of major scale. The following years all include maintenance costs that are a function of the amount of grass and drains in place as well as the cost of adding vertical drains and covering the newly developed sides. Every ten vertical meters, i.e., every two or three years, depending on the geometry of the stack and the rate of deposit of phosphogypsum, costs are incurred for the installation of peripheral drains. When the stack is closed, all costs for covering and seeding the top are incurred in that year. For scenario two, cover top and sides in the closure year, all costs for drains, cover, and seeding for the whole stack are incurred in a single year. Once the stack is closed, there is only an annual maintenance cost.

The only costs of control that increase as standards are made more stringent are those that are associated with the volume of dirt needed for coverage. All the costs of laying pipe, seeding and cover and drain maintenance are dependent on the geometry of the stack only and are incurred in any case in which control activity is required.

Appendix A to Chapter 9 lists the emission reductions and costs of attaining them by applying controls to the fourteen stacks. The costs, emissions after controls, and emission reductions are stated year by year for each of the fifty years, except that once the stack is closed the only cost is maintenance which is constant for the rest of the period. Showing each year's cost allows the pattern of costs and emission reductions to become apparent.

9.3.3.3 Emission Reductions Due to Controls

Reductions of radon emissions for each stack were computed by the computer program. For example, if the sides of a stack were covered with a thickness of dirt, then the R value associated with that thickness was multiplied by the product of the flux rate and area of the sides. If the sides were not covered, then emissions equal the product of the flux rate and the area of the sides. As stated above, the emission reductions from each stack over the fifty years considered will be larger than the minimum amount needed to just meet the standard.

The major difference between scenario 2 and scenario 1 is that in scenario 2, the sides are not covered while the stack is in operation. This does not reduce the monetary cost of coverage, but it does delay certain expenditures, sometimes for years, and there is no maintenance cost for those years. With regard to emissions under scenario 2 there is no emission reduction until the stack is closed. Again, this delay is often for many years. Differences with respect to standards are that the maximum allowable flux rates are cut by two thirds, to 2pCi/m^2/sec but the amount of dirt needed is just over twice as much.

9.3.3.4 Reduction of Risk Due to Controls

The benefit of the reduction in radon emissions is the reduction in the risk of lung cancer due to the emissions. Table 9-20 shows the reduction in risk to the most exposed individual and Table 9-21 shows the reduction in risk to the population within 80 km of each stack. Even though there are numerous technical details involved in measuring the exposures of the population and of the most exposed individual, including running the AIR-DOS computer code, these risks vary approximately in proportion to the emission rate from the stack in question. A single run of AIR-DOS was done using the initial emission levels. Changes in risk are computed using the proportional relationship. Therefore the reduction in allowable flux rates to 2 pCi/m^2/sec will reduce cancer rates to one third their level if the rate were 6 pCi/m^2/sec.

In computing the changes in risk to the population, the current emissions were assumed to continue for fifty years and the emissions with controls in place over those fifty years were totaled. The ratio of controlled to uncontrolled emissions was then computed and applied to the initial risks levels. In computing the changes in risk to the most exposed individual, the current emissions were distributed over seventy years, and seventy years of controlled emissions were totaled. The ratios of these values were used to compute the new risk levels.

9.4 Analysis of Benefits and Costs

9.4.1 Introduction

In this section the costs, emission reductions, and risk reductions are analyzed with respect to four combinations of scenarios and standard to establish their relative costs and benefits.

9.4.2 Least-Cost Control Technologies for Affected Plants

The options under consideration are to control to 20 pCi/m^2/sec, 6 pCi/m^2/sec, or 2 pCi/m^2/sec Control to 20 pCi/m^2/sec is based on risk levels for other industries, and the lower levels are studied to determine if a tighter standard is justified on economic grounds. The decision to require further control depends on the benefits, costs, and other considerations discussed below. In this section, cost of reduction of radon emissions from each stack per time period is the primary measure of

Table 9-20: Reduction in Risk to the Most Exposed Individual

STACK #	STACK # FROM TABLE 9-16	STATE	MAXIMUM LIFETIME FATAL CANCER RISK					REDUCTIONS (STD,SCNRO)			
			NO CONTROLS	WITH CONTROLS (STD,SCNRO)							
				2,1	2,2	6,1	6,2	2,1	2,2	6,1	6,2
1	5	Florida	1E-05	2.01E-06	2.11E-06	5.98E-06	6.05E-06	8E-06	8E-06	4E-06	4E-06
2	6	Florida	1E-05	2.45E-06	2.96E-06	6.41E-06	6.76E-06	8E-06	7E-06	4E-06	3E-06
3	11	Florida	5E-06	6.67E-07	6.67E-07	2.00E-06	2.00E-06	4E-06	4E-06	3E-06	3E-06
4	14	Florida	4E-05	6.84E-06	7.07E-06	1.99E-05	2.01E-05	3E-05	3E-05	2E-05	2E-05
5	18	Florida	1E-05	3.07E-06	4.36E-06	6.69E-06	7.59E-06	7E-06	6E-06	3E-06	2E-06
6	19	Florida	6E-05	1.02E-05	1.06E-05	2.98E-05	3.01E-05	5E-05	5E-05	3E-05	3E-05
7	21	Florida	2E-05	2.67E-06	2.67E-06	8.00E-06	8.00E-06	2E-05	2E-05	1E-05	1E-05
8	22	Idaho	9E-06	1.29E-06	1.29E-06	3.86E-06	3.86E-06	8E-06	8E-06	5E-06	5E-06
9	31	Illinois	4E-05	9.63E-06	1.17E-05	2.53E-05	2.68E-05	3E-05	3E-05	1E-05	1E-05
10	36	Louisiana	1E-06	1.33E-07	1.33E-07	4.00E-07	4.00E-07	9E-07	9E-07	6E-07	6E-07
11	42	Louisiana	7E-05	1.77E-05	2.25E-05	4.33E-05	4.67E-05	5E-05	5E-05	3E-05	2E-05
12	54	Texas	7E-05	2.19E-05	7.00E-05	3.67E-05	7.00E-05	5E-05	4E-11	3E-05	4E-11
13	55	Texas	8E-05	3.08E-05	8.00E-05	4.59E-05	8.00E-05	5E-05	0E+00	3E-05	0E+00
14	56	Texas	9E-05	1.72E-05	1.80E-05	5.09E-05	5.14E-05	7E-05	7E-05	4E-05	4E-05

Table 9-21: Reduction in Risk to Population within 80 km. of Stack

			COMMITTED FATAL CANCERS/YR (0-80 km)								
				WITH CONTROLS (STD,SCNRO)				REDUCTIONS (STD,SCNRO)			
STACK #	STACK # FROM TABLE 9-16	STATE	NO CONTROLS	2,1	2,2	6,1	6,2	2,1	2,2	6,1	6,2
1	5	Florida	6.0E-03	1.21E-03	1.29E-03	3.59E-03	3.64E-03	4.8E-03	4.7E-03	2.4E-03	2.4E-03
2	6	Florida	7.0E-03	1.81E-03	2.31E-03	4.51E-03	4.85E-03	5.2E-03	4.7E-03	2.5E-03	2.1E-03
3	11	Florida	1.0E-03	1.33E-04	1.33E-04	4.00E-04	4.00E-04	8.7E-04	8.7E-04	6.0E-04	6.0E-04
4	14	Florida	1.0E-02	1.73E-03	1.82E-03	4.99E-03	5.05E-03	8.3E-03	8.2E-03	5.0E-03	5.0E-03
5	18	Florida	2.0E-02	6.85E-03	1.05E-02	1.35E-02	1.60E-02	1.3E-02	9.5E-03	6.5E-03	4.0E-03
6	19	Florida	3.0E-02	5.20E-03	5.44E-03	1.49E-02	1.51E-02	2.5E-02	2.5E-02	1.5E-02	1.5E-02
7	21	Florida	3.0E-02	4.00E-03	4.00E-03	1.20E-02	1.20E-02	2.6E-02	2.6E-02	1.8E-02	1.8E-02
8	22	Idaho	9.0E-04	1.29E-04	1.29E-04	3.86E-04	3.86E-04	7.7E-04	7.7E-04	5.1E-04	5.1E-04
9	31	Illinois	3.0E-03	7.61E-04	9.81E-04	1.91E-03	2.06E-03	2.2E-03	2.0E-03	1.1E-03	9.4E-04
10	36	Louisiana	9.0E-04	1.20E-04	1.20E-04	3.60E-04	3.60E-04	7.8E-04	7.8E-04	5.4E-04	5.4E-04
11	42	Louisiana	3.0E-02	8.18E-03	1.11E-02	1.87E-02	2.08E-02	2.2E-02	1.9E-02	1.1E-02	9.2E-03
12	54	Texas	9.0E-02	2.82E-02	9.00E-02	4.72E-02	9.00E-02	6.2E-02	0.0E+00	4.3E-02	0.0E+00
13	55	Texas	1.0E-01	3.85E-02	1.00E-01	5.74E-02	1.00E-01	6.2E-02	0.0E+00	4.3E-02	0.0E+00
14	56	Texas	1.0E-01	1.93E-02	2.05E-02	5.65E-02	5.74E-02	8.1E-02	8.0E-02	4.3E-02	4.3E-02
		sum	4.3E-01	1.16E-01	2.48E-01	2.36E-01	3.28E-01	3.1E-01	1.8E-01	1.9E-01	1.0E-01
		avg	3.1E-02	8.29E-03	1.77E-02	1.69E-02	2.34E-02	2.2E-02	1.3E-02	1.4E-02	7.2E-03
		max	1.0E-01	3.85E-02	1.00E-01	5.74E-02	1.00E-01	8.1E-02	8.0E-02	4.3E-02	4.3E-02
		min	9.0E-04	1.20E-04	1.20E-04	3.60E-04	3.60E-04	7.7E-04	0.0E+00	5.1E-04	0.0E+00

effectiveness. Since no portion of any stack has a flux rate of more than 15.0 pCi/m^2/sec., well under the 20 pCi/m^2/sec limit, the choice is between 2 pCi/m^2/sec, 6 pCi/m^2/sec. or no control. Control costs and emission reductions for each stack under each standard are computed in the model. There are two scenarios to consider. The sides can be covered with dirt while the stack is operating and the top covered when the stack is closed (scenario 1), or the whole stack can be covered at closure of the stack (scenario 2). Table 9-22 shows the total emission reductions and cumulative discounted costs due to the emission reductions under each scenario and standard, for each stack and for all stacks taken together.

9.4.3. Health Benefits of Controlling Radon Emissions

Lung cancer rates are directly related to radon emissions. The issue is the size of the risks of lung cancer posed by phosphogypsum stacks and the reduction of the risk that will result from the control chosen. The AIRDOS computer code was run based on current estimates of emissions from the stacks. Two measures of risk were then calculated for each stack:

1. The risk to most exposed individual, usually one living near the base of a stack, measured as the number of chances per one million trials. This measure assumes the most exposed individual remains subject to the estimated radiation level for seventy years.
2. The probability that the general population will get cancer due to the stack's emissions, measured as the number of cases per one million persons. This measure considers the effects of one year of emissions on the population located within 80 km of each stack. The rule of thumb for estimating the risk to the entire U.S. is to double the risk to the 80 km population.

In cases where individuals may live within 80 km of more than one stack, the risk to the most exposed individual, shown in Table 9-20, was based upon only the closest stack. Risks to the 80 km populations were summed over all fourteen stacks. These are shown in Table 9-21.

9.4.4 Health Benefits and Cost Estimates

The greatest aggregate reduction in the risk of cancer in the 80 km region is obtained by setting the flux rate at 2 pCi/m^2/sec and requiring the sides of the stacks to be covered continuously as the stack grows (scenario one). The second greatest aggregate reduction is obtained with a flux rate of 6 pCi/m^2/sec and scenario one. Scenario two does not control emissions as effectively as scenario one primarily because several idle stacks will not grow to their maximum size (at least as long as they

TABLE 9-22: EFFECTIVENESS OF CONTROLS (Summed Over 50 Years)

			CUMULATIVE REDUCTIONS IN EMISSIONS DUE TO CONTROLS DIFFERENT STANDARDS, SCENARIO COMBINATIONS			
STACK #	STACK # FROM TABLE 9-16		STD=2,SCNRO=1 Ci	STD=2,SCNRO=2 Ci	STD=6,SCNRO=1 Ci	STD=6,SCNRO=2 Ci
1	5	Florida	3.2E+03	3.2E+03	1.9E+03	1.9E+03
2	6	Florida	2.8E+03	2.6E+03	1.7E+03	1.6E+03
3	11	Florida	4.6E+02	4.6E+02	4.6E+02	4.6E+02
4	14	Florida	7.2E+03	7.2E+03	4.3E+03	4.3E+03
5	18	Florida	1.1E+04	9.4E+03	6.6E+03	5.7E+03
6	19	Florida	1.3E+04	1.3E+04	7.6E+03	7.6E+03
7	21	Florida	1.2E+04	1.2E+04	7.0E+03	7.0E+03
8	22	Idaho	1.1E+03	0.0E+00	7.3E+02	0.0E+00
9	31	Illinois	3.5E+03	3.3E+03	2.1E+03	2.0E+03
10	36	Louisiana	6.8E+02	6.8E+02	4.4E+02	4.4E+02
11	42	Louisiana	5.4E+02	1.1E-02	3.4E+02	1.1E-02
12	54	Texas	1.6E+03	0.0E+00	9.7E+02	0.0E+00
13	55	Texas	2.1E+03	0.0E+00	1.2E+03	0.0E+00
14	56	Texas	5.8E+03	5.7E+03	3.5E+03	3.4E+03
		sum	6.4E+04	5.7E+04	3.9E+04	3.4E+04
		max	1.3E+04	1.3E+04	7.6E+03	7.6E+03
		min	4.6E+02	0.0E+00	3.4E+02	0.0E+00

TABLE 9-22: EFFECTIVENESS OF CONTROLS (Summed Over 50 Years)
(Continued)

STACK #	STACK # FROM TABLE 9-16	CUMULATIVE COST OF EMISSION REDUCTIONS IN NPV DIFFERENT STANDARDS, SCENARIO COMBINATIONS (discount rate = 0)			
		STD=2,SCNRO=1	STD=2,SCNRO=2	STD=6,SCNRO=1	STD=6,SCNRO=2
1	5	$10,216,062	$10,130,396	$6,588,331	$6,502,665
2	6	$10,556,218	$10,324,874	$6,697,169	$6,465,824
3	11	$11,642,131	$11,574,719	$11,642,131	$11,574,719
4	14	$33,821,479	$33,742,995	$21,453,771	$21,375,292
5	18	$44,146,277	$42,825,162	$27,510,276	$25,833,622
6	19	$59,547,383	$59,291,675	$37,757,329	$37,501,635
7	21	$58,933,036	$58,810,072	$37,475,256	$37,352,292
8	22	$4,054,347	$0	$2,316,907	$0
9	31	$16,141,632	$15,837,745	$9,474,176	$9,170,286
10	36	$2,822,379	$2,793,853	$1,990,128	$1,961,603
11	42	$82,571,649	$83,710,931	$56,923,789	$57,035,521
12	54	$5,482,067	$0	$3,499,779	$0
13	55	$7,040,622	$0	$4,476,860	$0
14	56	$21,295,139	$21,212,145	$13,507,061	$13,424,072
	Total Cost	$368,270,421	$350,254,568	$241,312,963	$228,197,531
	avg	$26,305,030	$25,018,183	$17,236,640	$16,299,824
	max	$82,571,649	$83,710,931	$56,923,789	$57,035,521
	min	$2,822,379	$0	$1,990,128	$0

TABLE 9-22: EFFECTIVENESS OF CONTROLS (Summed Over 50 Years)
(Continued)

STACK #	STACK # FROM TABLE 9-16	CUMULATIVE COST OF EMISSION REDUCTIONS IN NPV DIFFERENT STANDARDS, SCENARIO COMBINATIONS (discount rate =. 01)			
		STD=2,SCNRO=1	STD=2,SCNRO=2	STD=6,SCNRO=1	STD=6,SCNRO=2
1	5	$9,305,796	$9,179,842	$5,725,835	$5,623,591
2	6	$9,345,817	$8,946,252	$5,682,395	$5,382,484
3	11	$10,062,534	$10,000,281	$10,062,534	$10,000,281
4	14	$30,806,255	$30,660,220	$18,643,564	$18,536,209
5	18	$37,852,525	$35,163,892	$22,712,790	$20,528,238
6	19	$54,219,319	$53,863,408	$32,790,960	$32,502,717
7	21	$53,948,285	$53,827,744	$32,702,959	$32,582,417
8	22	$3,840,260	$0	$2,120,022	$0
9	31	$14,496,855	$13,891,433	$8,156,995	$7,734,146
10	36	$2,545,085	$2,518,741	$1,721,074	$1,694,731
11	42	$73,909,893	$74,575,890	$48,785,811	$48,685,000
12	54	$5,020,712	$0	$3,058,051	$0
13	55	$6,445,198	$0	$3,906,820	$0
14	56	$19,425,357	$19,271,601	$11,749,836	$11,636,983
	Total Cost	$331,223,890	$311,899,302	$207,819,644	$194,906,798
	avg	$23,658,849	$22,278,522	$14,844,260	$13,921,914
	max	$73,909,893	$74,575,890	$48,785,811	$48,685,000
	min	$2,545,085	$0	$1,721,074	$0

TABLE 9-22: EFFECTIVENESS OF CONTROLS (Summed Over 50 Years)
(Continued)

STACK #	STACK # FROM TABLE 9-16	CUMULATIVE COST OF EMISSION REDUCTIONS IN NPV DIFFERENT STANDARDS, SCENARIO COMBINATIONS (discount rate = .05)			
		STD=2,SCNRO=1	STD=2,SCNRO=2	STD=6,SCNRO=1	STD=6,SCNRO=2
1	5	$7,386,824	$7,114,867	$3,986,672	$3,824,408
2	6	$6,548,332	$5,636,277	$3,530,867	$3,024,320
3	11	$6,911,048	$6,865,421	$6,911,048	$6,865,421
4	14	$24,319,818	$23,928,961	$12,923,013	$12,711,090
5	18	$23,504,981	$17,393,402	$12,626,224	$9,220,181
6	19	$42,749,078	$42,015,546	$22,671,862	$22,251,337
7	21	$43,588,260	$43,476,727	$23,152,279	$23,040,746
8	22	$3,365,828	$0	$1,711,123	$0
9	31	$10,561,823	$9,032,556	$5,304,183	$4,519,757
10	36	$1,975,297	$1,955,990	$1,182,677	$1,163,370
11	42	$55,457,303	$54,445,872	$32,255,469	$31,402,650
12	54	$4,060,513	$0	$2,172,620	$0
13	55	$5,207,936	$0	$2,766,258	$0
14	56	$15,445,719	$15,035,505	$8,192,490	$7,971,494
	Total Cost	$251,082,759	$226,901,125	$139,386,784	$125,994,775
	avg	$17,934,483	$16,207,223	$9,956,199	$8,999,627
	max	$55,457,303	$54,445,872	$32,255,469	$31,402,650
	min	$1,975,297	$0	$1,182,677	$0

TABLE 9-22: EFFECTIVENESS OF CONTROLS (Summed Over 50 Years)
(Continued)

STACK #	STACK # FROM TABLE 9-16	CUMULATIVE COST OF EMISSION REDUCTIONS IN NPV DIFFERENT STANDARDS, SCENARIO COMBINATIONS (discount rate = .10)			
		STD=2,SCNRO=1	STD=2,SCNRO=2	STD=6,SCNRO=1	STD=6,SCNRO=2
1	5	$6,391,140	$5,966,223	$3,193,121	$2,968,098
2	6	$4,892,154	$3,596,385	$2,453,156	$1,796,110
3	11	$5,521,128	$5,489,680	$5,521,128	$5,489,680
4	14	$20,787,287	$20,139,886	$10,239,975	$9,918,644
5	18	$15,850,139	$8,079,766	$7,926,953	$4,012,127
6	19	$36,500,339	$35,352,529	$17,921,655	$17,344,232
7	21	$38,396,140	$38,294,516	$18,889,067	$18,787,444
8	22	$3,086,094	$0	$1,506,603	$0
9	31	$8,096,103	$5,865,783	$3,808,813	$2,755,365
10	36	$1,700,090	$1,686,782	$943,498	$930,191
11	42	$45,718,433	$43,019,302	$24,584,497	$22,977,672
12	54	$3,577,533	$0	$1,775,453	$0
13	55	$4,588,161	$0	$2,257,468	$0
14	56	$13,331,347	$12,652,399	$6,550,114	$6,215,975
	Total Cost	$208,436,087	$180,143,252	$107,571,501	$93,195,535
	avg	$14,888,292	$12,867,375	$7,683,679	$6,656,824
	max	$45,718,433	$43,019,302	$24,584,497	$22,977,672
	min	$1,700,090	$0	$943,498	$0

remain idle) and will therefore continue to emit from both their sides and top. Under scenario one, the tops of these stacks will not be covered but the sides are covered the first year.

Looking only at individual stacks that are open and growing and will be shut down in a few years, after reaching full size, the difference between scenario one and scenario two is minor. If scenario two is chosen, a requirement to cover the sides of idle stacks would reduce the number of fatal cancers per year significantly.

The pattern of reduction of cancer risks to the 80 km population evident in Table 9-21 deviates slightly from the pattern of emission reductions shown in Table 9-22. In particular, a standard of 2 pCi/m^2/sec combined with scenario two results in a larger reduction of emissions than a standard of 6 pCi/m^2/sec combined with scenario one. The reason is that each stack has a different number of persons living close to it and a different initial emission of radon. Thus emission reductions at each stack due to different policy options will have different relative effects on reduction of cancer risks.

With respect to costs, a flux rate of 2 pCi/m^2/sec combined with scenario one is the most costly, as shown in Table 9-22. Switching to scenario two results in a small reduction in cost while switching to 6 pCi/m^2/sec results in a larger cost reduction. A flux rate limit of 6 pCi/m^2/sec and scenario two is the least costly of the combinations studied.

9.4.5. Sensitivity Analysis

The ranking of the costs of the four combinations discussed in the preceding paragraph is not altered as the discount rate is changed. This was ascertained in Table 9-22 for discount rates of 0, 0.01, 0.05 and 0.10.

9.5 Industry Cost and Economic Impact Analysis

9.5.1. Introduction

Phosphogypsum is the major by-product of phosphate fertilizer production, an international industry. Historically, the United States was the world's chief supplier of the industry's raw and processed products. But as discussed in section 9.2, the United States' market share will decline sharply in the future due to rising costs of phosphate rock to U.S. producers -- as the better deposits are depleted -- and to improved supply of sulfuric acid to the United States' competitors.

In this section, two economic issues related to the control of radon emissions from phosphogypsum stacks are considered: 1) the increase in the cost of P_2O_5 production and 2) the impact these costs will have on the United States's economy and export revenues.

The analyses are performed using detailed data on the fourteen phosphogypsum stacks used in Tables 9-19 through 9-22. Two kinds of data are available for these stacks: first, production cost data for the P_2O_5 production associated with the stack and, second, the stack parameters required to assess the cost of controlling radon emissions from the stacks.

To estimate the effect of controls on U.S. exports a model was developed which estimates market shares for the U.S. and the rest of the world's P_2O_5 industry over the next thirty years in major regional markets. The model used two scenarios, one scenario using relatively lower U.S. phosphate rock costs in the production cost estimate and a second using relatively higher U.S. phosphate rock costs.

Radon control costs were produced by the model described in section 9.3 using stack parameters and input costs provided in section 9.3 and the appendix, respectively. For various discount rates, 0, .01, .05, and .10, the net present value (NPV) was calculated for the flow of costs and the annualized payment corresponding to each NPV was then computed. Annualized regulatory costs for each of the eleven producers -- which use the fourteen stacks -- per 1000 MT of P_2O_5 are provided in Table 9-23. In computing the annualized costs of the regulation, it was assumed that the NPV of the fifty year cost stream was paid off in the first five years the regulation was in effect. Five years roughly approximates the average remaining lifespan of the fourteen existing stacks.

9.5.2. Production Costs and Market Prices

The production cost data come from Zellars-Williams and are based on detailed descriptions of individual plant production functions. These data include both the expected quantities and prices of resources used in the production of P_2O_5, including sulphur, phosphate rock, and waste disposal; and credits for steam production and cogeneration of electricity. In addition, the source of the phosphate rock used by each plant is identified. Estimates for each variable are made for the years 1990, 1995, 2000, and 2005.

Trends in market prices for P_2O_5 are shown in Table 9-2 and Figure 9-1. An estimate of 1986 production costs for P_2O_5 is shown in Table 9-3. For 1986, the price of P_2O_5 (FOB U.S. Gulf)

TABLE 9-23: COST OF CONTROLLING RADON IN DOLLARS PER 1000/MT OF PLANT CAPACITY, ANNUALIZED OVER A FIVE YEAR PERIOD

	FACILITY #	STACK #	STACK # FROM TABLE 9-16	FACILITY NAME	STATE	CAPACITY (1000 MT/yr)	STATUS
*	1	1,2	5,6	Conserv, Inc.	Florida	180	Open
	2	3	11	Occidental Chemical Co. (Swift River)	Florida	340	Open
	3	4	14	Farmland Industries, Inc.	Florida	520	Open
	4	5	18	Agrico Chemical Co.	Florida	380	Open
	5	6	19	CF Industries, Inc.	Florida	760	Open
	6	7	21	IMC Corp.	Florida	1550	Open
**	7	8	22	J.R. Simplot Co.	Idaho	0	Idle
	8	9	31	Mobil Chemical Co.	Illinois	110	Open
	9	10	36	Beker Industries Corp.	Louisiana	420	Open
	10	11	42	Freeport Chemical Co.	Louisiana	800	Open
***	11	12,13,14	54,55,56	Mobil Mining and Minerals Division	Texas	220	Open

* -- Includes two stacks, each with a capacity of 90,000 MT/yr.

** -- This plant's only stack is idle, ie, zero effective capacity. Therefore, although costs were incurred, cost per unit of capacity is incalculable. The zeros in this record are not used in determining the plant with the minimum unit costs. However, the annualized costs to this firm are included in the "mean" figure.

*** -- This facility has three stacks, each with a capacity of 220,000 MT/yr. However, only one of the three stacks (# 12) is operating. Unit cost was calculated by dividing annualized cost by capacity of the operating stack.

**** -- sum of annualized costs divided by active yearly capacity.

TABLE 9-23 (cont'd): COST OF CONTROLLING RADON IN DOLLARS PER 1000 MT OF PLANT CAPACITY, ANNUALIZED OVER A FIVE YEAR PERIOD

	FACILITY	STACK #	STACK # FROM TABLE 9-16	STANDARD=2 SCENARIO=1			
				0	0.01	0.05	0.1
*	1	1,2	5,6	$23,080	$21,350	$17,881	$16,536
	2	3	11	$6,848	$6,098	$4,695	$4,284
	3	4	14	$13,008	$12,206	$10,802	$10,545
	4	5	18	$23,235	$20,524	$14,287	$11,003
	5	6	19	$15,670	$14,699	$12,992	$12,669
	6	7	21	$7,604	$7,171	$6,495	$6,535
**	7	8	22	---	---	---	---
	8	9	31	$29,348	$27,154	$22,177	$19,416
	9	10	36	$1,344	$1,249	$1,086	$1,068
	10	11	42	$20,643	$19,035	$16,012	$15,076
***	11	12,13,14	54,55,56	$30,743	$28,931	$25,947	$25,777
	aggregate annualized costs			$81,858,249	$79,002,947	$65,646,675	$60,947,215
		****	mean	$14,078	$12,949	$10,643	$9,713
			max	$30,743	$28,931	$25,947	$25,777
			min	$0	$0	$0	$0

r = discount rate.

* -- see first page of this table.

** -- see first page of this table.

*** -- see first page of this table.

**** -- see first page of this table.

TABLE 9-23 (cont'd): COST OF CONTROLLING RADON IN DOLLARS PER 1000 MT OF PLANT CAPACITY, ANNUALIZED OVER A FIVE YEAR PERIOD

	FACILITY	STACK #	STACK # FROM TABLE 9.3-1	STANDARD=2 SCENARIO=2			
				"r" = 0	"r" = .01	"r" = .05	"r" = .10
*	1	1,2	5,6	$22,728	$20,748	$16,362	$14,014
	2	3	11	$6,809	$6,060	$4,664	$4,259
	3	4	14	$12,978	$12,149	$10,629	$10,217
	4	5	18	$22,540	$19,066	$10,572	$5,609
	5	6	19	$15,603	$14,603	$12,769	$12,271
	6	7	21	$7,588	$7,155	$6,479	$6,517
**	7	8	22	---	---	---	---
	8	9	31	$28,796	$26,020	$18,966	$14,067
	9	10	36	$1,330	$1,236	$1,076	$1,059
	10	11	42	$20,928	$19,207	$15,720	$14,185
***	11	12,13,14	54,55,56	$19,284	$18,049	$15,786	$15,171
aggregate annualized costs				$78,125,118	$71,152,272	$56,084,043	$49,173,474
		****	mean	$14,417	$13,117	$10,275	$8,852
			max	$28,796	$26,020	$18,966	$15,171
			min	$0	$0	$0	$0

r = discount rate.

* -- see first page of this table.

** -- see first page of this table.

*** -- see first page of this table.

**** -- see first page of this table.

TABLE 9-23 (cont'd): COST OF CONTROLLING RADON IN DOLLARS PER 1000 MT OF PLANT CAPACITY, ANNUALIZED OVER A FIVE YEAR PERIOD

				STANDARD=6 SCENARIO=1			
	FACILITY	STACK #	STACK # FROM TABLE 9-16	"r" = 0	"r" = .01	"r" = .05	"r" = .10
*	1	1,2	5,6	$14,762	$13,059	$9,646	$8,275
	2	3	11	$6,848	$6,098	$4,695	$4,284
	3	4	14	$8,251	$7,387	$5,740	$5,195
	4	5	18	$14,479	$12,315	$7,675	$5,503
	5	6	19	$9,936	$8,890	$6,890	$6,221
	6	7	21	$4,836	$4,347	$3,450	$3,215
**	7	8	22	---	---	---	---
	8	9	31	$17,226	$15,279	$11,138	$9,134
	9	10	36	$948	$844	$650	$593
	10	11	42	$14,231	$12,565	$9,313	$8,107
***	11	12,13,14	54,55,56	$19,531	$17,527	$13,786	$12,690
			aggregate annualized costs	$53,796,222	$47,968,432	$36,356,225	$31,970,295
		****	mean	$10,095	$8,937	$6,635	$5,747
			max	$19,531	$17,527	$13,786	$12,690
			min	$0	$0	$0	$0

r = discount rate.
* -- see first page of this table.
** -- see first page of this table.
*** -- see first page of this table.
**** -- see first page of this table.

TABLE 9-23 (cont'd): COST OF CONTROLLING RADON IN DOLLARS PER 1000/MT OF PLANT CAPACITY, ANNUALIZED OVER A FIVE YEAR PERIOD

	FACILITY	STACK #	STACK # FROM TABLE 9-16	STANDARD=6 SCENARIO=2			
				"r" = 0	"r" = .01	"r" = .05	"r" = .10
*	1	1,2	5,6	$14,409	$12,598	$8,788	$6,982
	2	3	11	$6,809	$6,060	$4,664	$4,259
	3	4	14	$8,221	$7,345	$5,646	$5,032
	4	5	18	$13,597	$11,131	$5,604	$2,785
	5	6	19	$9,869	$8,812	$6,762	$6,020
	6	7	21	$4,820	$4,331	$3,433	$3,197
**	7	8	22	---	---	---	---
	8	9	31	$16,673	$14,487	$9,490	$6,608
	9	10	36	$934	$831	$640	$584
	10	11	42	$14,259	$12,539	$9,067	$7,577
***	11	12,13,14	54,55,56	$12,204	$10,899	$8,369	$7,453
	aggregate annualized costs			$51,006,427	$44,867,499	$32,080,992	$26,517,566
		****	mean	$9,254	$8,094	$5,679	$4,591
			max	$16,673	$14,487	$9,490	$7,577
			min	$0	$0	$0	$0

r = discount rate.

* -- see first page of this table.

** -- see first page of this table.

*** -- see first page of this table.

**** -- see first page of this table.

averaged \$279.38 per metric ton and the estimated production costs totaled \$263.88. P_2O_5 prices for the first half of 1988 averaged \$306.50. While these prices and costs are snapshots of a highly variable market, they are consistent in estimating the order of magnitude of the costs of producing P_2O_5.

Runs of the control cost model, the results of which are displayed in Table 9-23, produced annualized radon emission control costs per 1000 MT of P_2O_5 for each combination of emission flux standard, scenario and discount rate. For each plant the most costly combination of these factors was considered. For all runs, the highest cost per 1000 MT of P_2O_5 production of controlling radon emissions, from any of the eleven plants is estimated to be \$30.74 per ton of P_2O_5. This amounts to 12 per cent of the 1986 production cost, 11 per cent of the 1986 average price, and 10 per cent of the average price for the first half of 1988. The smallest maximum annualized cost of radon emission control at any plant was \$1.34. While the larger of these cost increases is significant, the ultimate economic impact depends on the effects of the increases on the domestic and international markets.

9.5.3. Measuring Economic Impacts

9.5.3.1 Background

The approach to measuring the economic impacts of controlling radon emissions from phosphogypsum stacks used in this section is to trace the initial round of effects on the U.S. economy. The initial round of effects is generally the largest and easiest to identify. Adjustments made by the rest of the world will not be traced in this section.

First round effects include changes in the relative price and real output of P_2O_5, which lead directly to:

- changes in the prices and amounts of the inputs to P_2O_5 used, including phosphate rock, sulfuric acid, land and labor;
- changes in the amounts of resources used in the transportation of these inputs and outputs;
- changes in the amounts of P_2O_5 exported and in the trade balance and foreign exchange related to these exports.

These first round effects are discussed below. The nature of economic effects in further rounds of adjustment will depend on the opportunity cost of using resources in P_2O_5 production and the substitutability of other products for P_2O_5. For example, if a decline in the sale and profitability of P_2O_5 produced in Florida led to decisions not to begin new phosphogypsum stacks, the land that would have been used for the stack becomes available for other purposes. If these other purposes create economic activity then the new activity should be added to the ledger as the economic activity attributable to the stack is subtracted. The activity attributable to the alternative use is the opportunity cost of using the land for a stack. If the opportunity cost is relatively high, then the loss due to not proceeding with the stack is relatively low, but if opportunity costs for using a resource are low, then the loss of economic activity from not being able to open it is relatively high.

A concept related to this is the unemployment of resources. If resources have a low utilization rate, then the reduction in economic activity of not using them in P_2O_5 production is high as alternative uses are not available and the resources become idle. In short, the economic impact of a change in usage of P_2O_5 plants will depend on the level to which resources are employed in the vicinities of the plants affected by the controls.

9.5.3.2. Changes in Quantity of P_2O_5 Produced Due to Control Requirements

Changes in the quantity of P_2O_5 produced in the United States will be a direct result of the change in production costs attributable to the regulations. A reduction will take place if domestic producers of P_2O_5 lack the ability or inclination to absorb the cost increase and therefore raise their prices relative to the level they would have charged in the absence of regulation. As was described in section 9.2, the phosphate fertilizer industry during the 1980s has generally experienced decreased demand and lower relative prices. As a consequence some companies have sold their phosphate fertilizer plants or gone out of business. This economic history makes it unlikely that producers will be able or willing to absorb the cost of the controls.

Domestic producers are expected to pass on the cost of the controls. These price increases are unlikely to jeopardize U.S. producers hold on the domestic market. The cost of production of foreign producers, including transportation costs to the U.S., do not make foreign producers competitive in the U.S. market, even after the controls. Since there is no direct substitute for phosphate fertilizer, the reduction in domestic demand for phosphate fertilizer because of the increase in price will be limited. Because there is no good estimate of the price elasticity of demand for phosphate fertilizer, it is not possible to estimate the magnitude of this effect.

It is possible to estimate the effect of the controls on U.S. market share in the rest of the world. When the specific costs of controlling radon emissions from phosphogypsum stacks are added to the production costs of U.S. producers, but not to those of foreign producers, shifts in market shares result. The magnitude of the changes are not readily predictable from the average control costs computed above, because of variation in the control costs faced by each plant and because a firm's share of a market is not affected until the price at which it can supply the product exceeds the lowest price at which a competing firm or nation is willing to offer the product. To determine the impact of radon control costs on world markets, a model of world P_2O_5 markets was constructed and is described below.

9.5.3.3 Methodology for Estimating Economic Impacts

Over the next thirty years, a host of factors will influence the level of production, prices and trade patterns that will develop for phosphate products. Demand for fertilizer will increase at different rates around the world. New production capacity will be built; sources of phosphate rock and sulfur and the prices of those products will change. Transportation costs between importing and exporting countries will change. To analyze these relationships and to develop a basis from which to estimate the cost of the controls on the phosphate industry over the next 30 years, a computer model was developed for this study. Below is a description of the model and the forecasts made with it.

Model Structure

The model developed to analyze these uncertainties uses the sources described in section 9.2. In particular, the model makes use of plant-specific production cost estimates from Zellars-Williams, alternative phosphate rock mining costs from William Stowasser at the Bureau of Mines, and phosphate fertilizer demand estimates from WEFA.

The model contains forecasts of production levels, production costs, transportation costs and demand for six regions and the United States. Production forecasts are not available beyond the year 2005. Consequently, production forecasts for 2018 were produced separately and combined with the others.

WPPA is sold in several forms. Some countries purchase the acid and domestically produce various fertilizers while other countries purchase finished fertilizers, such as diammonium phosphate. For simplicity, the model considers only phosphoric acid production costs. This implicitly assumes that no exporting country has a comparative advantage in producing various fertilizers.

The model considers the production and transport costs of each supplier and ranks the lowest to highest suppliers for each region. Each supplier is assumed to maximize profits by supplying those regions where its costs are lowest. Thus, if Morocco is the lowest cost supplier in more regions than it can supply, Morocco is assumed to favor markets where its transportation costs are lowest.

The model is modified to allow for some special cases where noncompetitive domestic production is assumed to receive special support to overcome foreign competition. The model does not, however, consider cases where state-owned enterprises may export below cost for prolonged periods in order to obtain foreign exchange. This possibility is a serious concern to many in the phosphate industry because much of the foreign competition is state owned. Nevertheless, it is not possible to reliably forecast political influences on financial decisions.

A detailed description of the methodology, data sources and assumptions used in the forecasting model is given in Appendix B.

Forecast of Trade Levels Without Controls

Two scenarios, a lower phosphate rock cost, and a higher phosphate rock cost, were developed for the model. The only variable changed between the scenarios is the cost of mining phosphate rock in the United States. As was described in section 9.2, this factor is of primary importance in determining the outlook for the phosphate fertilizer industry. The lower phosphate rock cost scenario uses phosphate rock mining cost estimates developed by Zellars-Williams (ZW) and the higher phosphate rock costs scenario uses rock mining cost estimates developed by experts at the U.S. Bureau of Mines.

The higher phosphate rock cost, lower exports, scenario anticipates export levels in 1990 of 6.5 million tons. This scenario predicts exports will decline to 3.7 million tons in 1995 and continue declining to 1.8 million tons in the year 2000 and 0.6 million tons in 2005. The U.S. is expected to stop exporting phosphate fertilizer products sometime after 2005 and before 2018. Tables 9-24 and 9-25 show these forecasts for both scenarios by region. Because the model could not incorporate all the factors which influence the regional trade levels, the regional forecasts are not as reliable as the aggregate forecast.

The lower phosphate rock cost, higher exports, scenario uses the same rock cost estimates for 1990 as the previous forecast and consequently anticipates identical export levels in 1990. In 1995, export levels are forecast to decline to 4.5 million tons. In the years 2000, 2005 and 2018, exports are forecast to be 2.9, 1.9 and 0.6 million tons, respectively. Thus, the lower phosphate rock costs scenario forecasts a similar trend as the previous scenario but forecasts a slower rate of decline in

TABLE 9-24A: WORLD MARKET SHARES OF U.S. P205 PRODUCERS EXPORTS IN ABSENCE OF RADON CONTROL MEASURES (in 1000 MT)
Lower Phosphate Rock Costs

	1990	1995	2000	2005	2018
LAT. AMER	771	422	338	187	0
W. EUROPE	940	832	987	433	620
E. EUROPE	488	448	121	0	0
S. C. ASIA	565	806	0	0	0
E. ASIA	2,901	1,204	520	310	0
OCEANIA	860	827	906	979	0
TOTAL AMOUNT	6,525	4,539	2,872	1,909	620

TABLE 9-24B: WORLD MARKET SHARES OF U.S. P205 PRODUCERS EXPORTS WITH MOST EXPENSIVE RADON CONTROL MEASURES (in 1000 MT)

	1990	1995	2000	2005	2018
LAT. AMER	771	422	0	0	0
W. EUROPE	508	0	0	0	0
E. EUROPE	608	0	0	0	0
S. C. ASIA	508	0	0	0	0
E. ASIA	1,933	1,995	1,764	619	0
OCEANIA	860	827	0	0	0
TOTAL AMOUNT	5,188	3,244	1,764	619	0

TABLE 9-24C: DIFFERENCE IN WORLD MARKET SHARES OF US P205 EXPORTS DUE TO MOST EXPENSIVE RADON CONTROL MEASURES (in 1000 MT)

	1990	1995	2000	2005	2018
LAT. AMER	0	0	(338)	(187)	0
W. EUROPE	(432)	(832)	(987)	(433)	(620)
E. EUROPE	120	(448)	(121)	0	0
S. C. ASIA	(57)	(806)	0	0	0
E. ASIA	(968)	791	1,244	309	0
OCEANIA	0	0	(906)	(979)	0
TOTAL AMOUNT	(1,337)	(1,295)	(1,108)	(1,290)	(620)

TABLE 9-25A: WORLD MARKET SHARES OF U.S. P205 PRODUCERS EXPORTS
IN ABSENCE OF RADON CONTROL MEASURES (in 1000 MT)
Higher Phosphate Rock Costs

	1990	1995	2000	2005	2018
LAT. AMER	771	422	0	0	0
W. EUROPE	940	272	0	0	0
E. EUROPE	488	0	0	0	0
S. C. ASIA	565	0	0	0	0
E. ASIA	2,901	2,187	1,764	620	0
OCEANIA	860	827	0	0	0
TOTAL AMOUNT	6,525	3,708	1,764	620	0

TABLE 9-25B: WORLD MARKET SHARES OF U.S. P205 PRODUCERS EXPORTS
WITH MOST EXPENSIVE RADON CONTROL MEASURES
(in 1000 MT)

	1990	1995	2000	2005	2018
LAT. AMER	771	422	0	0	0
W. EUROPE	608	0	0	0	0
E. EUROPE	508	0	0	0	0
S. C. ASIA	508	0	0	0	0
E. ASIA	2,151	1,995	1,764	620	0
OCEANIA	860	827	0	0	0
TOTAL AMOUNT	5,406	3,244	1,764	620	0

TABLE 9-25C: DIFFERENCE IN WORLD MARKET SHARES OF US P205 EXPORTS
DUE TO MOST EXPENSIVE RADON CONTROL MEASURES

	1990	1995	2000	2005	2018
LAT. AMER	0	0	0	0	0
W. EUROPE	(332)	(272)	0	0	0
E. EUROPE	20	0	0	0	0
S. C. ASIA	(57)	0	0	0	0
E. ASIA	(750)	(192)	0	0	0
OCEANIA	0	0	0	0	0
TOTAL AMOUNT	(1,119)	(464)	0	0	0

export levels. Several important factors shed light on the model's forecasts. As explained in section 9.2, U.S. producers are expected to experience marginally higher costs for sulfur and North Africa is expected to have a similar decrease in costs. Changing sulfur costs accounts for a $10 to $15 per ton shift in phosphoric acid production costs between the U.S. and the major competitors in North Africa. The most important factor influencing the pessimistic outlook for U.S. phosphate exports is the cost of mining phosphate rock. Even the lower phosphate rock costs scenario allows for an increase in phosphate rock costs for U.S. producers over time.

Forecast of Trade Levels With Controls

To estimate the trade impacts of the proposed controls, both scenarios of the model were run with the added costs of the controls included. For each U.S. plant, the highest cost option for that plant that was calculated in the previous section was added to the production cost of that plant in the model. The forecasts are shown in Tables 9-24 and 9-25. The forecasts for trade levels with and without the controls under the lower phosphate rock costs scenario are also illustrated on Figure 9-4. In the lower phosphate rock costs scenario, the controls are projected to decrease exports by 1.3 million tons in 1990. This effect remains at 1.3 million tons in the year 1995, 1.1 million tons in the year 2000, 1.3 million in 2005,and drop to 0.6 million tons by 2018. Assuming a continuous change in export levels during the years not specifically forecast, the controls are forecast to decrease exports by 31.0 million tons over the next 30 years using the lower phosphate rock costs scenario.

Using the higher phosphate rock costs scenario, the controls are forecast to decrease exports by 1.1 million tons in 1990 and by 464,000 tons in 1995. No effect on exports is projected by the year 2000 and beyond. Assuming a continuous change in export levels during the years not specifically forecast, the controls are forecast to decrease exports by 5.1 million tons over the next 30 years using the lower phosphate rock costs scenario. The forecasts for trade levels with and without the controls under the higher phosphate rock costs scenario are illustrated on Figure 9-5.

Balance of Trade

The effects of the decrease in exports of phosphate products on the trade balance depends to some extent on the form in which the phosphoric acid is exported. If the phosphoric acid is exported directly, the loss in export revenue is approximately $307.50 per ton of P_2O_5 (1988 dollars). If the phosphoric acid is first converted into phosphate fertilizer, the loss in export revenue is greater. For example, diammonium phosphate (DAP) uses 0.478 tons of P_2O_5 to produce per ton of DAP. DAP sold for $188.60 per ton in 1988. Thus, the decrease in export level from a one ton decrease in P_2O_5

Figure 9-4: U.S. P2O5 EXPORTS
Assuming Lower Phosphate Rock Costs

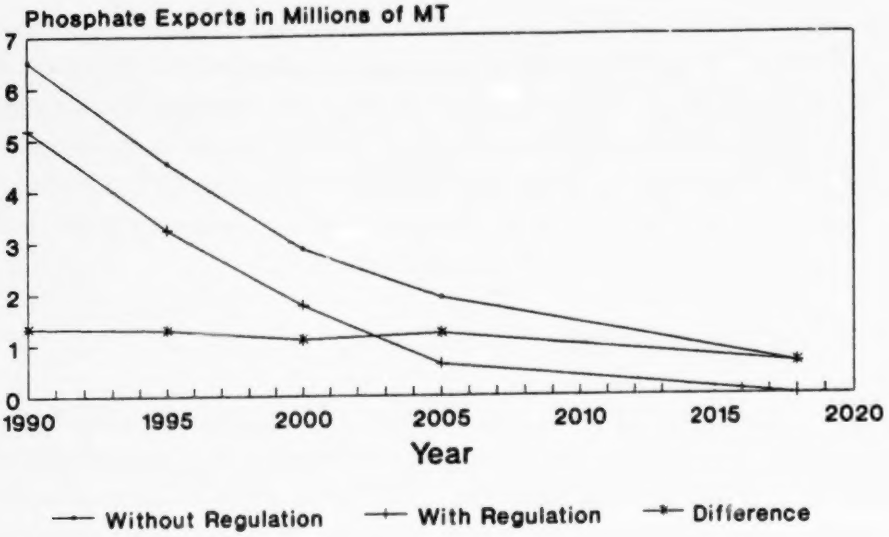
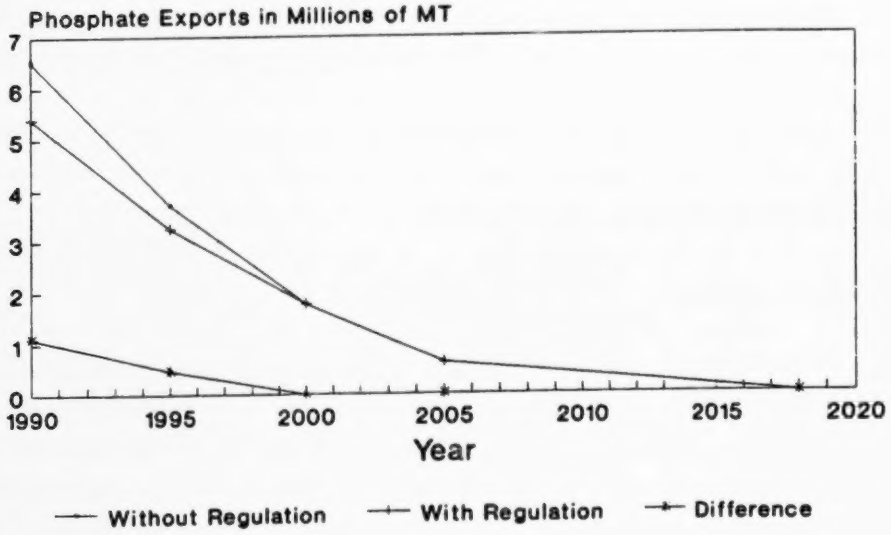


Figure 9-5: U.S. P2O5 EXPORTS
Assuming Higher Phosphate Rock Costs



exports that has been converted into DAP is approximately $394.50 per ton of P_2O_5 (1988 dollars). In 1985, 17.8 percent of the revenue from phosphate products came from the export of P_2O_5 and 82.2 percent came from the export of finished fertilizer. Because the preponderance of P_2O_5 is exported as finished fertilizer and the principal phosphate fertilizer is DAP, the revenue effects of the controls are described in terms of a weighted average of P_2O_5 and DAP exports.

The two scenarios predict that the effect on export revenue in 1990 will be a reduction in export revenue of $410 million for the low cost scenario and $343 million for the high cost. The higher phosphate rock cost, lower export, scenario predicts that the cumulative revenue loss over the next 30 years will be $1.4 billion. The lower rock costs, higher export, scenario predicts that the cumulative revenue loss will be $9.5 billion. The revenue loss in the higher rock cost scenario is limited to the next ten years, with no loss in exports by the year 2000 and beyond. These estimated economic impacts of the standard are obviously dependent upon the many assumptions in developing the model that are described in Appendix B. The export revenue effects of the standard in the early years of the controls are much more reliable than the forecasts for 20 or 30 years in the future. The decrease in export revenues in 1990 is estimated to be approximately a little under one half a billion dollars. A revenue loss of this magnitude would continue were it not for the general decline in phosphate exports that is forecast in both scenarios.

9.5.3.4. Other Impacts of Radon Control Requirements on the U.S. Economy

The shifts in the markets for P_2O_5 are the most notable direct effects of radon control costs. However, there are some spinoffs as noted above. These are discussed below.

Inputs: Sulfuric Acid

Most sulfuric acid used in the production of P_2O_5 is the by-product of other activities such as removal of sulfur from gas or oil. Reductions in the demand for sulfuric acid for use in P_2O_5 production would reduce the prices at which this residual could be sold, and thereby increase the net costs of oil and gas desulfurization. These effects are expected to be minor.

Inputs: Phosphate Rock

Phosphate rock is exported to some of the world's other P_2O_5 producing nations. If the United States loses some exports of P_2O_5 to other countries due to increased regulatory costs, it is likely that exports of phosphate rock to these nations will increase. This will mitigate some of the losses of revenue that would accompany loss of P_2O_5 markets. In many cases the increased sale of phosphate rock will bring revenues to the same firms that lost revenue due to declines in P_2O_5 sales. These effects, however, will be short term because the U.S. is not expected to remain a significant phosphate rock exporter for many years.

Inputs: Labor

Since the value of labor required to produce P_2O_5 is a small proportion of the total value of all inputs, the absolute size of the shift in the labor market will be small. This small impact may be magnified or diminished by the local employment situation. In areas that are experiencing economic growth, there will be demand for labor that will be able to absorb the relatively small number of persons affected. This is especially true in Florida, where population growth can be expected to generate demands for increased levels of construction activity, and where the largest concentration of workers in the P_2O_5 industry is clustered. It should also be noted that the regulations require increased ongoing activity in the form of the labor and other employment of resources and equipment needed to lay drains on the stacks, move and place dirt on the stacks, and maintain the cover and drains. The first two activities will occur so long as any stacks remain open and the last will be required for all closed stacks.

Inputs: Land

The land for existing stacks is already in use and its quantity and location will not be changed by the regulation. The regulation could affect the decision to start new stacks and would therefore affect the land requirements in the future.

Transportation

Some reduction in the transportation of P_2O_5 exports can be anticipated. On the other hand, increased transportation of phosphate rock will partially mitigate the reduction. However, since most transport of these materials is by foreign-owned ships, this reduction will not affect U.S. interests.

9.6 Regulatory Flexibility Analysis

9.6.1 Introduction

The Regulatory Flexibility Act was signed into law on September 19, 1980. Its purpose is to call to the attention of federal agency personnel any impacts on small "entities" such as small business, small organizations, or small governmental jurisdictions that may unduly hamper them. The hope of the law's authors was that if federal agencies were aware of negative impacts on small entities due to a rulemaking, they would modify the rule, if possible, to reduce the damage.

Two kinds of small entities are potentially affected by the rulemaking on phosphogypsum stacks: small business and small government. However, the analysis below shows that entities falling under the definition of the act are not adversely affected in a significant way.

9.6.2 Small Business

The business entities directly affected by the phosphogypsum rules under consideration are large corporations. They include large, internationally operated chemical companies, oil firms and fertilizer producers. For most of these firms, P_2O_5 production is but one of numerous activities including phosphate rock mining and processing, fertilizer production, or chemical production. The amount of investment and risk involved in these productions is large, too large for a firm that could qualify as a small business to engage in.

9.6.3 Small Governmental Entities

The definition of a small county is one with less than 50,000 citizens. However, the counties in Florida with the highest concentration of phosphoric acid production have greater than 50,000 citizens.

REFERENCES

AMA82 Amax Corporation, annual reports, 1982, 1985, 1986.

An88 Conversation with Neil Anderson of Mobil Mining and Minerals, 6/14/88.

Ba82 Babitzke, Herbert R., Barsotti, Aldo F., Coffman, Joseph S., Thompson, Jerrold G., and Bennett, Harold J. *The Bureau of Mines Minerals Availability System: An Update of Information Circular 8654 (IC 8887)*, Bureau of Mines, 1982.

Bo83a Boyd, B.W. *Sulphur and Sulphuric Acid: Where is Canada Headed?*, Canada, Department of Energy, Mines and Resources, Mineral Policy Sector, July 1983.

Bo83b Boyd, B.W. *Sulphur Market Profile*, Canada Department of Energy, Mines and Resources, Mineral Policy Sector, December 14, 1983.

BOMa Bureau of Mines, Department of the Interior, *Resource Reserve Definitions: Principles of a Resource/Reserve Classification for Minerals*. (joint publication with U.S. Geological Survey).

BOMb ____________. *Sedimentary Phosphate Resource Classification System of the U.S. Bureau of Mines and the U.S. Geological Survey*, Circular #882, n.d., p.3.

BOM70 ____________. *Minerals Yearbook*, 1970, 1972, 1974, 1975, 1978-79, 1980, 1982, 1984, 1985.

BOM84 ____________. *Phosphate Rock Availability - World*, 1984.

BOM87a ____________. *An Appraisal of Minerals Availability for 34 Commodities*, 1987.

BOM87b ____________. *Mineral Commodity Summaries*, 1987.

BOM87c ____________. *Mineral Commodity Survey*, 1987.

BOM87d ____________. "Phosphate Rock 1987 Crop Year," *Mineral Industry Survey*, August 19, 1987.

BOM88a ____________. "Directory of Companies Producing Phosphate Rock in the United States--1988," *Mineral Industry Survey*, January 25, 1988.

BOM88b ____________. "End Uses of Sulfur and Sulfuric Acid in 1987," *Mineral Industry Surveys*, June 17, 1988.

BOM88c ____________. "Marketable Phosphate Rock," *Mineral Industry Survey*, January, February, and March 1988 issues.

BOM88d ____________. "Phosphate Rock in 1987," *Mineral Industry Survey*, January 4, 1988.

BOM88e ____________. "Sulfur," *Mineral Commodity Summaries*, 1988.

BOM88f ____________. "Sulfur in April 1988," *Mineral Industry Survey*, June 3, 1988.

BOM88g	____________. *World Demand for Fertilizer Nutrients for Agriculture, OFR 24-88*, prepared by Wharton Econometric Forecasting Associates, April 1988.
Br82	____________. "Phosphate," *Fertilizer Trends*, pp. 19-28, NFDC/TVA, 1982.
Br86	Bridges, Darwin. *Fertilizer Trends*, National Fertilizer Development Center, Tennessee Valley Authority, 1986.
BSC	British Sulfur Corporation, *World Guide to Fertilizer, Processes and Constructors*, List of world nitrophosphates and phosphates production facilities, phosphate rock treatment, phosphogypsum processing, other phosphorus and phosphoric acid-related firms.
BSC85a	____________. "Export Prices," *Phosphorus and Potassium*, November-December 1985, pp. 10-12.
BSC85b	____________. "False Hopes for Superphosphoric Acid," *Phosphorus and Potassium*, November-December 1985, pp. 6-7.
BSC85c	____________. "The Florida Phosphate Industry in Transition," *Phosphorus and Potassium*, November-December 1985, pp. 25-27.
BSC85d	____________. "Freights: Rates Holding a Steady Course," *Phosphorus and Potassium*, November-December 1985, pp. 13-14.
BSC85e	____________. *World Fertilizer Products: World Statistics*, June 1985.
BSC85f	____________. "Long-term Price Trends--Stability Returns," *Phosphorus and Potassium*, November-December 1985, p. 4.
BSC85g	____________. "World Markets," *Phosphorus and Potassium*, November-December 1985, pp. 15-17.
BSC85h	____________. "Phosphogypsum, a Source of Sulfur Dioxide: New Signs of Life?" *Phosphorus and Potassium* # 137, May-June 1985.
BSC85i	____________. *World Sulphur Resources*, 3rd ed., 1985.
BSC86a	____________. "Morocco Develops Its P2O5 Industry," *Sulphur*, May-June 1986, pp. 24-25.
BSC86b	____________. "Sulphuric Acid--Supply/Demand Prospects," *Sulphur*, January-February 1986, p. 5.
BSC86c	____________. *World Directory of Fertilizer Manufacturers*, photocopy of chapter on United States, 1986.
BSC86d	____________. *Availability of Elemental Sulfur and Pyrite Concentrate--Market Economy Countries: A Minerals Availability Appraisal*. Bureau of Mines Information Circular IC 9106, 1986.
BSC87	British Sulphur Corporation. "Dealing with Mining Wastes in the Phosphate Industry," *Phosphorus and Potassium*, September-October 1987.

BSC87a ____________. "Phosphate Fertilizer Outlook Unlikely to Lift Sulphur Demand," *Sulphur*, November-December 1987, p. 5.

BSC87b ____________. *Phosphorus and Potassium*, various issues.

BSC87c ____________. "The Search for Backhauls," *Phosphorus and Potassium*, March-April 1987.

BSC87d ____________. "Will the Market Turn Around in 1987?", *Sulphur*, January-February 1987.

BSC87e ____________. *World Fertilizer News Summary*, June 1987.

BSC87f ____________. "Sulfuric Acid from Phosphogypsum: Will It Ever Impact the Sulfur Market?" *Sulfur*, July-August 1987.

BSC87g ____________. "Phosphogypsum: The Newest Sulphur Resource." *Sulphur* # 190, May-June 1987.

BSC87h ____________. "Phosphogypsum: The Newest Sulphur Resource." Lloyd, G.M., Kendron, T.J., and Marten, J.H., *Sulphur* No. 190, May-June 1987, p. 30.

BSC88a ____________. "World Markets" *Phosphorus and Potassium*, March-April, 1988.

BSC88b British Sulphur Corp., Data purchased by Jack Faucett Associates, July 5, 1988.

Bu86 Buckingham, D.A. "The Availability of U.S. Frasch Sulphur," *Industrial Minerals*, January 1988.

Ch87 Chang, Wen. *Reclamation, Reconstruction and Reuse of Phosphogypsum for Building Materials*. Prepared by University of Miami under a grant from the Florida Institute of Phosphate Research. January, 1987.

Ch88 Conversation with Mr. Chang, 7/5/88.

CMR86 Chemical Marketing Reporter. "Phosphoric Acid Bid Launched by Monsanto and FMC Corporation," *Chemical Marketing Reporter*, December 1, 1986.

CHV83 Chevron Corporation, annual reports, 1983, 1984, 1985, 1986.

DOC82a ____________. *Census of Manufacturers*, 1982: General Summary.

DOC82b ____________. *Census of Mineral Industries*, 1982; Subject Series.

DOC83 Department of Commerce, Bureau of the Census. *Annual Survey of Manufacturers*, 1983.

DOC87 ____________. "Inorganic Fertilizer Materials and Related Products", *Current Industrial Reports*: Seasonal adjustment supplement, 1966 to 1976;Summary for 1973; Summary for 1976; Summary for 1978; Summary for 1979; January 1982; January 1983; 1985; 1986; September 1987; November 1987.

DOC80 ____________. *Current Industrial Reports*. "Phosphatic Fertilizer Materials": Summary for 1980.

DOC81 ____________. *Current Industrial Reports*. "Sulfuric Acid": 1981; 1984; 1988.

DOC84 ____________. "Agricultural Chemicals," 1983 U.S. Industrial Outlook, January 1983.

DOC86a ____________. *U.S. Exports*, 1986.

DOC86b ____________. *1985 Annual Survey of Manufacturers. Expenditures for Plant and Equipment.* Bureau of the Census.

DOC88a ____________. *U.S. Industrial Outlook*, 1988.

DOC88b *Survey of Current Business*, Bureau of Economic Analysis, Department of Commerce, August 1988.

DOC88c State Population Projections, Bureau of the Census. Most recent revised forecast as of 7/5/1988.*

Co87 J.W. Couston. *Current World Fertilizer Situation and Outlook, 1985/86-1991/92.* FAO Commission on Fertilizers, 1987.

CYA81 Cyanamid Corporation, annual reports, 1981, 1982, 1983, 1985, 1986, 1987.

Da88 Dayton, Stanley L. "Phosphate Rock: World Output Increases, Prices Weaken and Competition Intensifies," *Engineering and Mining Journal*, April 1988.

Ec88 Eckert, G.F. "Sulphur Demand Improves Slowly," *Engineering and Mining Journal*, April 1988.

ELF84 Elf Aquitaine Inc., annual reports, 1984, 1985, 1986, 1987.

EIA85 ____________. *Petroleum Supply Annual 1984*, Volume 2, June 1985.

EIA86 Energy Information Administration, Department of Energy. *Annual Energy Outlook 1985, With Projections to 1995*, February 1986.

EIA87a ____________. *Petroleum Supply Annual 1986*, June 1987.

EIA87b ____________. *Short-term Energy Outlook, Annual Supplement 1987*, October 1987.

EIA88 *Annual Energy Outlook 1987.* Energy Information Administration, Department of Energy, March 28, 1988, p. 39 and 40. Base case forecasts were used.

EPA82 ____________. *Phosphate Rock Plants--Background Information for Promulgated Standards (EPA-450/3-79-01 7b).* Office of Air, Noise and Radiation, EPA April 1982.

EPA84 Environmental Protection Agency. *Radionuclide: Background information Document for Final Rules, 52011-84-022-1*, October 1984.

Fa83 Fantel, R.J., Sullivan, D.E., and Peterson, G.R. *Phosphate Rock Availability--Domestic; A Minerals Availability Program Appraisal (IC 8937).* Bureau of Mines, August 1983.

Fa84 Fantel, R.J., Anstett, T.F., Peterson, G.R., Porter, K.E. and Sullivan, D.E. *Phosphate Rock Availability--World; A Minerals Availability Program Appraisal (IC 8989).* Bureau of Mines, 1984.

Fa85 R.J. Fantel, G.R. Peterson, and W.F. Stowasser (Bureau of Mines, Department of the Interior). "The Worldwide Availability of Phosphate Rock," *Natural Resources Forum*, FAO/UN, 1985.

FAO85 *Fertilizer Yearbook*, Food and Agriculture Organization, United Nations, 1985 and 1986.

FI183 Farmland Industries Inc., annual reports, 1983, 1984, 1985, 1986, 1987.

FF83 Fertilizer Focus: "Focus on Tampa--No. 1 in Phosphates," *Fertilizer Focus*, April 1, 1983.

FF85 ____________. "Focus on: Phoschem Aims for Stability in Phosphates Market," *Fertilizer Focus*, September 1985, p 18.

FF87a ____________. "Focus on Phosphoric Acid Trade," *Fertilizer Focus*, October 1987.

FF87b ____________. "Opinion: The Acid Freight Market in 1986," *Fertilizer Focus*, January 1987.

FIP85 Florida Institute of Phosphate Research. *Proceedings of the Second Workshop on By-Products of Phosphate Industries*, conducted by the Department of Civil and Architectural Engineering, University of Miami, under a grant sponsored by the Florida Institute of Phosphate Research, May, 1985.

FIP86a ____________. *DAP Quality Seminar* (Publication No. 01-000-041), conducted by Florida Institute of Phosphate Research, Tennessee Valley Authority, and The Fertilizer Institute, August 1986.

FIP86b ____________. *Proceedings of the Third Workshop on By-Products of Phosphate Industries*, conducted by the Department of Civil and Architectural Engineering, University of Miami, under a grant sponsored by the Florida Institute of Phosphate Research, November, 1986.

FIP88 ____________. *Proceedings of the Second International Symposium on Phosphogypsum*, organized by the University of Miami under a grant from the Florida Institute of Phosphate Research, January, 1988 (two volumes).

FIP ____________. *Publications*. Florida Institute of Phosphate Research.

FMI82 Freeport McMoRan Inc., annual reports, 1982, 1983. 1984, 1985, 1986.

Ga85 Galvin, James J. "The U.S. Phosphate Industry," *Fertilizer Focus*, June 1985.

GAO79 General Accounting Office. *Phosphates: A Case Study of a Valuable, Depleting Mineral in America*, November 30, 1979 (GA0 # 80-21).

Gr86 W.R. Grace & Co., annual report, 1986, 1987 second quarter report.

GM87 Green Markets. *Green Markets Trade Overview*, May 18, 1987.

GM88a Green Markets. *Monthly Statistical Supplement*, March 28, 1988.

GM88b Green Markets. "Sales, profits, production up in last half of 1987 in North America," *Green Markets*, March 7, 1988.

GM88c Green Markets. "Dispute between U.S. Bureau of Mines, industry, comes to a head," *Green Markets*, February 8, 1988.

GM88d Green Markets. "Grace sells 28 more retail outlets, granulation plant could go this month," *Green Markets*, March 21. 1988.

GM88e Green Markets. "Freeport resuming construction of pilot gypsum conversion plant," *Green Markets*, March 21, 1988.

Ha80 Harre, E.A. and Isherwood, K.F., "World Phosphate Fertilizer Supply-Demand Outlook." Ch. 8 in Khasawneh et. al. *The Role of Phosphorus in Agriculture*, 1980.

Ha87 Harre, Edwin. *Emerging Trends in the World Phosphate Market*. NFDC/TVA, September 1987.

Hr83 Hrabik, Joseph A., and Godesky, Douglas J. *Economic Evaluation of Borehole and Conventional Mining Systems in Phosphate Deposits (IC 8929)*. Bureau of Mines, 1983.

IMC87 International Minerals and Chemicals Co., annual report 1987.

IMF87 International Monetary Fund. *International Financial Statistics Yearbook*, 1987.

KAI82 Kaiser Aluminum & Chemicals Corporation, annual reports, 1982, 1983, 1984, 1985, 1986.

Ke86 Kendron, T.J. (Davy McKee Corp.) and Lloyd, G.M. (Florida Institute of Phosphate Research). *Phosphogypsum to Sulfuric Acid With Cogeneration--A Competitive Edge*. Paper presented at the Second International Symposium on Phosphogypsum, December, 1986.

Ke87 King, Harriet, and Wilson, Linda J. "The Boom in Phosphate Bans," *Chemical Week*, June 3, 1987.

Ll85 Lloyd, G. Michael Jr. *Phosphogypsum: A Review of the Florida Institute of Phosphate Research Programs to Develop Uses for Phosphogypsum*, Florida Institute of Phosphate Research, December 1985.

Ll88 Mike Lloyd, Florida Institute of Phosphate Research, Personal Communications, March 18, 1988.

MAN85	Mannsville Chemical Products Corporation. "Phosphoric Acid (Wet Process)," *Chemical Products Synopsis*, December 1985.
Mc87a	McGinty, Robert. "Phosphate Producers Prepare for a Comeback," *Chemical Week*, June 10, 1987.
Mc87b	____________. "Phosphate Producers Seek a Tax Cut," *Chemical Week*, June 3, 1987.
Mc87c	____________. "A New Way to Undercut Phosphogypsum Stacks," *Chemical Week*, July 8, 1987.
Mc88	Conversation with James McGinnis of Simplot Corp., 6/16/88.
Mn88	Conversation with James Moon, Jacobs Engineering, 7/1/1988.
MOB86	Mobil Corporation, annual report 1986.
MON85	Montedison Group, annual reports, 1985, 1986, 1987.
Mo88a	Morse, David E. *Mineral Commodity Summaries, 1988*, Bureau of Mines, 1988.
Mo88b	Personal communications with David Morse, Bureau of Mines, June 14, 1988 and with J.S. Platou, The Sulfur Institute, June 14, 1988.
Mo85	____________. "Sulfur," *Minerals Yearbook*, Bureau of Mines, 1985 and 1986 preprint.
MO87	Morris, R.J. "The World Market for Plant Nutrient Sulphur," *Sulphur/87*, 1987, pp. 5-22.
Ph88	Phillips, Robert Q. *Canada's Position in World Sulphur Markets*, paper presented at 39th Annual Technical Meeting of The Petroleum Society of CIM, June 13th, 1988.
Pl87	Platou, J.S. "The Competitive Position of Sulphuric Acid vs. Nitric Acid for Phosphate Fertilizer Production," *Sulphur/87*, 1987, pp.203-218.
Pl88	Conversation with J.S. Platou, The Sulphur Institute, August 2, 1988.
Ri87	Rivoire, John. "For Fertilizers, the Worst is Over," *Chemical Week*, July 8, 1987.
Ru87	Russell, Alison. "Phosphate Rock: Trends in Processing and Production," *Industrial Minerals*, September 1987.
RP86	Rhone-Poulenc, annual report 1986.
Sp83	Spangenberg, Dale R., Carey, Edward F., and Takosky, Paula M. *Minerals Availability Commodity Directory on Phosphate (IC 8926).* Bureau of Mines, 1983.
SRI85	SRI International, *Animal Feeds, Phosphate Supplements*, March 1985, p. 201.
SRI86	____________. *Agricultural Phosphate Industrial Overview*, September 1986.
St85	Stowasser, William. "Phosphate Rock," *Mineral Facts and Problems, 1985 Edition* (Bureau of Mines Bulletin 675), Bureau of Mines.

St86a ____________. "Phosphate Rock," preprint from the 1986 *Minerals Yearbook*, Bureau of Mines.

St86b ____________. *Phosphate Rock: World Resources, Supply and Demand*. Bureau of Mines, 1986.

Te87 Teleki, Deneb. "The Outlook for North American Fertilizers," *Fertilizer Focus*, Feb. 1987.

TFI86a The Fertilizer Institute. *Ammonia Production Cost Survey, Year Ended December 31, 1986* (compiled by National Fertilizer Development Center, Economics and Marketing Staff, Tennessee Valley Authority).

TFI86b ____________. *Fertilizer Facts and Figures*, Vol 1986, No.1. September 1986.

TFI87b ____________. *Fertilizer Financial Facts for Year Ended December 31, 1986* (compiled by National Fertilizer Development Center, TVA), May 1, 1987.

TFI88 ____________. *Fertilizer Record*, January 1988 (production and disappearance data, January 1988).

TFI87c ____________. *Phosphate Fertilizer Production Cost Survey, Year Ended December 31, 1986* (compiled by National Fertilizer Development Center, Economics and Marketing Staff, Tennessee Valley Authority), May 1, 1987.

TFI87d ____________. *Phosphate Rock Production Cost Survey, Year Ended December 31, 1986* (compiled by National Fertilizer Development Center, Economics and Marketing Staff, Tennessee Valley Authority), May 1, 1987.

TFI87e ____________. Memo from Whitney Yelverton containing summary data for fiscal year 1987. October 1987.

Tu83 Turner, Billie. "Obstacles to International P2O5 Trade and Measures Required to Promote Its Growth," *Fertilizer Focus*, September 1983.

Tu87 Tully, J.J. and Ziebold, S.A. "Economics of Manufacture of Sulfuric Acid from Pyrites Compared to Sulfur," *Sulphur/87*, 1987, pp. 219-234.

TVA88 *North American Fertilizer Capacity Data*. National Fertilizer Development Center, Tennessee Valley Authority, July 1988.

USD83 ____________. *Commercial Fertilizers, Consumption for Year Ended June 30 1983*, Crop Reporting Board, November 1983.

USD86 ____________. Fertilizers-price to farmer and average crop/fertilizer price ratios, 1977-1986. ASCS, USDA.

USD87a United States Department of Agriculture. *Agricultural Prices*, October 1987.

USD87b ____________. *Agricultural Resources: Inputs, Situation and Outlook Report*. Economic Research Service, January 1987.

USD87c ____________. *Economic Indicators of the Farm Sector Costs of Production*, 1986, Economic Research Service, Nov. 1987.

USD87d ____________. *Farm Production Expenditures 1986 Summary*, National Agricultural Statistics Survey, July 1987.

USD87e ____________. *Agricultural Statistics 1986*, Washington: GPO, 1987, (see Tables 532 and 585).

USS82 United States Steel, annual reports, 1982, 1983, 1984, 1985.

USX86 USX Corporation, annual reports, 1986, 1987.

Vr86 Vroomen, Harry. *Fertilizer Use and Price Statistics, 1960-85*, Economic Research Service, USDA.

WH87 Wharton Econometric Forecasting Associates. *U.S. and World Fertilizer Service Long-Term Forecast and Analysis*. No.1, 1987.

WH88 *World Demand for Fertilizer Nutrients for Agriculture*, prepared by The WEFA Group, Wharton Econometric Forecasting Associates, for the Bureau of Mines, Dept. of Interior, OFR-24-88, April 1988.

WI86 The Williams Companies (owners of Agrico Chemical Company), annual reports 1984, 1985, 1986.

WB86 World Bank. *World Development Report 1986*, Oxford University Press, 1986.

Ye88 Personal communication with Whitney Yelverton, The Fertilizer Institute, March 29, 1988.

ZE86 Zellars-Williams Co. *Phosphate Rock 1985/86: A Multiclient Study by Zellars-Williams Co.*, June 1986.

Appendix A:

Notes to Appendix A

The calculations presented in Appendix A are described in Section 9.3.3. Costs are accrued as horizontal and vertical drain pipes are laid, as dirt cover is added, and as annual maintenance is carried out. The major costs occur at closing when the tops are covered and, in Scenario One, in the first year when the existing sides are covered. Further coverage of the sides occurs as the stacks grow. The only cost after closure is for maintenance.

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 1
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = .995

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	614,711.1	1,317,454.0	$4,316,410
2	409,857.9	2,049,289.0	$2,197,487
3	409,857.9	2,049,289.0	$111,128
4	409,857.9	2,049,289.0	$76,405
5	409,857.9	2,049,289.0	$76,405
6	409,857.9	2,049,289.0	$76,405
7	409,857.9	2,049,289.0	$76,405
8	409,857.9	2,049,289.0	$76,405
9	409,857.9	2,049,289.0	$76,405
10	409,857.9	2,049,289.0	$76,405
11	409,857.9	2,049,289.0	$76,405
12	409,857.9	2,049,289.0	$76,405
13	409,857.9	2,049,289.0	$76,405
14	409,857.9	2,049,289.0	$76,405
15	409,857.9	2,049,289.0	$76,405
16	409,857.9	2,049,289.0	$76,405
17	409,857.9	2,049,289.0	$76,405
18	409,857.9	2,049,289.0	$76,405
19	409,857.9	2,049,289.0	$76,405
20	409,857.9	2,049,289.0	$76,405
21	409,857.9	2,049,289.0	$76,405
22	409,857.9	2,049,289.0	$76,405
23	409,857.9	2,049,289.0	$76,405
24	409,857.9	2,049,289.0	$76,405
25	409,857.9	2,049,289.0	$76,405
26	409,857.9	2,049,289.0	$76,405
27	409,857.9	2,049,289.0	$76,405
28	409,857.9	2,049,289.0	$76,405
29	409,857.9	2,049,289.0	$76,405
30	409,857.9	2,049,289.0	$76,405
31	409,857.9	2,049,289.0	$76,405
32	409,857.9	2,049,289.0	$76,405
33	409,857.9	2,049,289.0	$76,405
34	409,857.9	2,049,289.0	$76,405
35	409,857.9	2,049,289.0	$76,405
36	409,857.9	2,049,289.0	$76,405
37	409,857.9	2,049,289.0	$76,405
38	409,857.9	2,049,289.0	$76,405
39	409,857.9	2,049,289.0	$76,405
40	409,857.9	2,049,289.0	$76,405
41	409,857.9	2,049,289.0	$76,405
42	409,857.9	2,049,289.0	$76,405
43	409,857.9	2,049,289.0	$76,405
44	409,857.9	2,049,289.0	$76,405
45	409,857.9	2,049,289.0	$76,405
46	409,857.9	2,049,289.0	$76,405
47	409,857.9	2,049,289.0	$76,405
48	409,857.9	2,049,289.0	$76,405
49	409,857.9	2,049,289.0	$76,405
50	409,857.9	2,049,289.0	$76,405

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 2
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = .995

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	993,836.9	602,931.3	$1,959,538
2	956,465.9	681,670.4	$91,304
3	917,843.4	763,046.1	$534,857
4	877,780.5	847,456.5	$46,429
5	836,037.1	935,407.9	$581,340
6	792,286.9	1,027,588.0	$56,025
7	746,080.0	1,124,943.0	$644,854
8	386,833.5	1,934,167.0	$3,228,241
9	386,833.5	1,934,167.0	$81,277
10	386,833.5	1,934,167.0	$81,277
11	386,833.5	1,934,167.0	$81,277
12	386,833.5	1,934,167.0	$81,277
13	386,833.5	1,934,167.0	$81,277
14	386,833.5	1,934,167.0	$81,277
15	386,833.5	1,934,167.0	$81,277
16	386,833.5	1,934,167.0	$81,277
17	386,833.5	1,934,167.0	$81,277
18	386,833.5	1,934,167.0	$81,277
19	386,833.5	1,934,167.0	$81,277
20	386,833.5	1,934,167.0	$81,277
21	386,833.5	1,934,167.0	$81,277
22	386,833.5	1,934,167.0	$81,277
23	386,833.5	1,934,167.0	$81,277
24	386,833.5	1,934,167.0	$81,277
25	386,833.5	1,934,167.0	$81,277
26	386,833.5	1,934,167.0	$81,277
27	386,833.5	1,934,167.0	$81,277
28	386,833.5	1,934,167.0	$81,277
29	386,833.5	1,934,167.0	$81,277
30	386,833.5	1,934,167.0	$81,277
31	386,833.5	1,934,167.0	$81,277
32	386,833.5	1,934,167.0	$81,277
33	386,833.5	1,934,167.0	$81,277
34	386,833.5	1,934,167.0	$81,277
35	386,833.5	1,934,167.0	$81,277
36	386,833.5	1,934,167.0	$81,277
37	386,833.5	1,934,167.0	$81,277
38	386,833.5	1,934,167.0	$81,277
39	386,833.5	1,934,167.0	$81,277
40	386,833.5	1,934,167.0	$81,277
41	386,833.5	1,934,167.0	$81,277
42	386,833.5	1,934,167.0	$81,277
43	386,833.5	1,934,167.0	$81,277
44	386,833.5	1,934,167.0	$81,277
45	386,833.5	1,934,167.0	$81,277
46	386,833.5	1,934,167.0	$81,277
47	386,833.5	1,934,167.0	$81,277
48	386,833.5	1,934,167.0	$81,277
49	386,833.5	1,934,167.0	$81,277
50	386,833.5	1,934,167.0	$81,277

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 3
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = .333

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	354,356.6	291,323.3	$4,635,814
2	354,356.6	291,323.3	$141,610
3	354,356.6	291,323.3	$141,610
4	354,356.6	291,323.3	$141,610
5	354,356.6	291,323.3	$141,610
6	354,356.6	291,323.3	$141,610
7	354,356.6	291,323.3	$141,610
8	354,356.6	291,323.3	$141,610
9	354,356.6	291,323.3	$141,610
10	354,356.6	291,323.3	$141,610
11	354,356.6	291,323.3	$141,610
12	354,356.6	291,323.3	$141,610
13	354,356.6	291,323.3	$141,610
14	354,356.6	291,323.3	$141,610
15	354,356.6	291,323.3	$141,610
16	354,356.6	291,323.3	$141,610
17	354,356.6	291,323.3	$141,610
18	354,356.6	291,323.3	$141,610
19	354,356.6	291,323.3	$141,610
20	354,356.6	291,323.3	$141,610
21	354,356.6	291,323.3	$141,610
22	354,356.6	291,323.3	$141,610
23	354,356.6	291,323.3	$141,610
24	354,356.6	291,323.3	$141,610
25	354,356.6	291,323.3	$141,610
26	354,356.6	291,323.3	$141,610
27	354,356.6	291,323.3	$141,610
28	354,356.6	291,323.3	$141,610
29	354,356.6	291,323.3	$141,610
30	354,356.6	291,323.3	$141,610
31	354,356.6	291,323.3	$141,610
32	354,356.6	291,323.3	$141,610
33	354,356.6	291,323.3	$141,610
34	354,356.6	291,323.3	$141,610
35	354,356.6	291,323.3	$141,610
36	354,356.6	291,323.3	$141,610
37	354,356.6	291,323.3	$141,610
38	354,356.6	291,323.3	$141,610
39	354,356.6	291,323.3	$141,610
40	354,356.6	291,323.3	$141,610
41	354,356.6	291,323.3	$141,610
42	354,356.6	291,323.3	$141,610
43	354,356.6	291,323.3	$141,610
44	354,356.6	291,323.3	$141,610
45	354,356.6	291,323.3	$141,610
46	354,356.6	291,323.3	$141,610
47	354,356.6	291,323.3	$141,610
48	354,356.6	291,323.3	$141,610
49	354,356.6	291,323.3	$141,610
50	354,356.6	291,323.3	$141,610

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 4
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	2,716,696.0	2,029,631.0	$7,048,714
2	926,363.2	4,631,816.0	$14,964,290
3	926,363.2	4,631,816.0	$246,010
4	926,363.2	4,631,816.0	$246,010
5	926,363.2	4,631,816.0	$246,010
6	926,363.2	4,631,816.0	$246,010
7	926,363.2	4,631,816.0	$246,010
8	926,363.2	4,631,816.0	$246,010
9	926,363.2	4,631,816.0	$246,010
10	926,363.2	4,631,816.0	$246,010
11	926,363.2	4,631,816.0	$246,010
12	926,363.2	4,631,816.0	$246,010
13	926,363.2	4,631,816.0	$246,010
14	926,363.2	4,631,816.0	$246,010
15	926,363.2	4,631,816.0	$246,010
16	926,363.2	4,631,816.0	$246,010
17	926,363.2	4,631,816.0	$246,010
18	926,363.2	4,631,816.0	$246,010
19	926,363.2	4,631,816.0	$246,010
20	926,363.2	4,631,816.0	$246,010
21	926,363.2	4,631,816.0	$246,010
22	926,363.2	4,631,816.0	$246,010
23	926,363.2	4,631,816.0	$246,010
24	926,363.2	4,631,816.0	$246,010
25	926,363.2	4,631,816.0	$246,010
26	926,363.2	4,631,816.0	$246,010
27	926,363.2	4,631,816.0	$246,010
28	926,363.2	4,631,816.0	$246,010
29	926,363.2	4,631,816.0	$246,010
30	926,363.2	4,631,816.0	$246,010
31	926,363.2	4,631,816.0	$246,010
32	926,363.2	4,631,816.0	$246,010
33	926,363.2	4,631,816.0	$246,010
34	926,363.2	4,631,816.0	$246,010
35	926,363.2	4,631,816.0	$246,010
36	926,363.2	4,631,816.0	$246,010
37	926,363.2	4,631,816.0	$246,010
38	926,363.2	4,631,816.0	$246,010
39	926,363.2	4,631,816.0	$246,010
40	926,363.2	4,631,816.0	$246,010
41	926,363.2	4,631,816.0	$246,010
42	926,363.2	4,631,816.0	$246,010
43	926,363.2	4,631,816.0	$246,010
44	926,363.2	4,631,816.0	$246,010
45	926,363.2	4,631,816.0	$246,010
46	926,363.2	4,631,816.0	$246,010
47	926,363.2	4,631,816.0	$246,010
48	926,363.2	4,631,816.0	$246,010
49	926,363.2	4,631,816.0	$246,010
50	926,363.2	4,631,816.0	$246,010

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 5
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = .995

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	4,430,001.0	2,465,139.0	$8,008,838
2	4,356,343.0	2,620,333.0	$238,847
3	4,281,658.0	2,777,689.0	$1,092,557
4	4,205,897.0	2,937,315.0	$137,726
5	4,128,984.0	3,099,367.0	$1,134,498
6	4,050,865.0	3,263,959.0	$151,884
7	3,971,441.0	3,431,302.0	$1,180,547
8	3,890,629.0	3,601,567.0	$166,738
9	3,808,326.0	3,774,978.0	$1,231,922
10	3,724,417.0	3,951,769.0	$182,426
11	3,638,763.0	4,132,239.0	$1,289,906
12	3,551,212.0	4,316,704.0	$199,164
13	3,461,588.0	4,505,538.0	$1,356,614
14	3,369,674.0	4,699,194.0	$217,249
15	1,658,091.0	8,290,455.0	$15,032,080
16	1,658,091.0	8,290,455.0	$357,865
17	1,658,091.0	8,290,455.0	$357,865
18	1,658,091.0	8,290,455.0	$357,865
19	1,658,091.0	8,290,455.0	$357,865
20	1,658,091.0	8,290,455.0	$357,865
21	1,658,091.0	8,290,455.0	$357,865
22	1,658,091.0	8,290,455.0	$357,865
23	1,658,091.0	8,290,455.0	$357,865
24	1,658,091.0	8,290,455.0	$357,865
25	1,658,091.0	8,290,455.0	$357,865
26	1,658,091.0	8,290,455.0	$357,865
27	1,658,091.0	8,290,455.0	$357,865
28	1,658,091.0	8,290,455.0	$357,865
29	1,658,091.0	8,290,455.0	$357,865
30	1,658,091.0	8,290,455.0	$357,865
31	1,658,091.0	8,290,455.0	$357,865
32	1,658,091.0	8,290,455.0	$357,865
33	1,658,091.0	8,290,455.0	$357,865
34	1,658,091.0	8,290,455.0	$357,865
35	1,658,091.0	8,290,455.0	$357,865
36	1,658,091.0	8,290,455.0	$357,865
37	1,658,091.0	8,290,455.0	$357,865
38	1,658,091.0	8,290,455.0	$357,865
39	1,658,091.0	8,290,455.0	$357,865
40	1,658,091.0	8,290,455.0	$357,865
41	1,658,091.0	8,290,455.0	$357,865
42	1,658,091.0	8,290,455.0	$357,865
43	1,658,091.0	8,290,455.0	$357,865
44	1,658,091.0	8,290,455.0	$357,865
45	1,658,091.0	8,290,455.0	$357,865
46	1,658,091.0	8,290,455.0	$357,865
47	1,658,091.0	8,290,455.0	$357,865
48	1,658,091.0	8,290,455.0	$357,865
49	1,658,091.0	8,290,455.0	$357,865
50	1,658,091.0	8,290,455.0	$357,865

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 6
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	4,794,927.0	3,550,362.0	$12,172,590
2	1,627,573.0	8,137,861.0	$26,451,610
3	1,627,573.0	8,137,861.0	$433,433
4	1,627,573.0	8,137,861.0	$433,433
5	1,627,573.0	8,137,861.0	$433,433
6	1,627,573.0	8,137,861.0	$433,433
7	1,627,573.0	8,137,861.0	$433,433
8	1,627,573.0	8,137,861.0	$433,433
9	1,627,573.0	8,137,861.0	$433,433
10	1,627,573.0	8,137,861.0	$433,433
11	1,627,573.0	8,137,861.0	$433,433
12	1,627,573.0	8,137,861.0	$433,433
13	1,627,573.0	8,137,861.0	$433,433
14	1,627,573.0	8,137,861.0	$433,433
15	1,627,573.0	8,137,861.0	$433,433
16	1,627,573.0	8,137,861.0	$433,433
17	1,627,573.0	8,137,861.0	$433,433
18	1,627,573.0	8,137,861.0	$433,433
19	1,627,573.0	8,137,861.0	$433,433
20	1,627,573.0	8,137,861.0	$433,433
21	1,627,573.0	8,137,861.0	$433,433
22	1,627,573.0	8,137,861.0	$433,433
23	1,627,573.0	8,137,861.0	$433,433
24	1,627,573.0	8,137,861.0	$433,433
25	1,627,573.0	8,137,861.0	$433,433
26	1,627,573.0	8,137,861.0	$433,433
27	1,627,573.0	8,137,861.0	$433,433
28	1,627,573.0	8,137,861.0	$433,433
29	1,627,573.0	8,137,861.0	$433,433
30	1,627,573.0	8,137,861.0	$433,433
31	1,627,573.0	8,137,861.0	$433,433
32	1,627,573.0	8,137,861.0	$433,433
33	1,627,573.0	8,137,861.0	$433,433
34	1,627,573.0	8,137,861.0	$433,433
35	1,627,573.0	8,137,861.0	$433,433
36	1,627,573.0	8,137,861.0	$433,433
37	1,627,573.0	8,137,861.0	$433,433
38	1,627,573.0	8,137,861.0	$433,433
39	1,627,573.0	8,137,861.0	$433,433
40	1,627,573.0	8,137,861.0	$433,433
41	1,627,573.0	8,137,861.0	$433,433
42	1,627,573.0	8,137,861.0	$433,433
43	1,627,573.0	8,137,861.0	$433,433
44	1,627,573.0	8,137,861.0	$433,433
45	1,627,573.0	8,137,861.0	$433,433
46	1,627,573.0	8,137,861.0	$433,433
47	1,627,573.0	8,137,861.0	$433,433
48	1,627,573.0	8,137,861.0	$433,433
49	1,627,573.0	8,137,861.0	$433,433
50	1,627,573.0	8,137,861.0	$433,433

EFFECTS OF CONTROLS FOR STACK 7
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,475,431.0	7,377,153.0	$37,895,730
2	1,475,431.0	7,377,153.0	$549,788
3	1,475,431.0	7,377,153.0	$426,823
4	1,475,431.0	7,377,153.0	$426,823
5	1,475,431.0	7,377,153.0	$426,823
6	1,475,431.0	7,377,153.0	$426,823
7	1,475,431.0	7,377,153.0	$426,823
8	1,475,431.0	7,377,153.0	$426,823
9	1,475,431.0	7,377,153.0	$426,823
10	1,475,431.0	7,377,153.0	$426,823
11	1,475,431.0	7,377,153.0	$426,823
12	1,475,431.0	7,377,153.0	$426,823
13	1,475,431.0	7,377,153.0	$426,823
14	1,475,431.0	7,377,153.0	$426,823
15	1,475,431.0	7,377,153.0	$426,823
16	1,475,431.0	7,377,153.0	$426,823
17	1,475,431.0	7,377,153.0	$426,823
18	1,475,431.0	7,377,153.0	$426,823
19	1,475,431.0	7,377,153.0	$426,823
20	1,475,431.0	7,377,153.0	$426,823
21	1,475,431.0	7,377,153.0	$426,823
22	1,475,431.0	7,377,153.0	$426,823
23	1,475,431.0	7,377,153.0	$426,823
24	1,475,431.0	7,377,153.0	$426,823
25	1,475,431.0	7,377,153.0	$426,823
26	1,475,431.0	7,377,153.0	$426,823
27	1,475,431.0	7,377,153.0	$426,823
28	1,475,431.0	7,377,153.0	$426,823
29	1,475,431.0	7,377,153.0	$426,823
30	1,475,431.0	7,377,153.0	$426,823
31	1,475,431.0	7,377,153.0	$426,823
32	1,475,431.0	7,377,153.0	$426,823
33	1,475,431.0	7,377,153.0	$426,823
34	1,475,431.0	7,377,153.0	$426,823
35	1,475,431.0	7,377,153.0	$426,823
36	1,475,431.0	7,377,153.0	$426,823
37	1,475,431.0	7,377,153.0	$426,823
38	1,475,431.0	7,377,153.0	$426,823
39	1,475,431.0	7,377,153.0	$426,823
40	1,475,431.0	7,377,153.0	$426,823
41	1,475,431.0	7,377,153.0	$426,823
42	1,475,431.0	7,377,153.0	$426,823
43	1,475,431.0	7,377,153.0	$426,823
44	1,475,431.0	7,377,153.0	$426,823
45	1,475,431.0	7,377,153.0	$426,823
46	1,475,431.0	7,377,153.0	$426,823
47	1,475,431.0	7,377,153.0	$426,823
48	1,475,431.0	7,377,153.0	$426,823
49	1,475,431.0	7,377,153.0	$426,823
50	1,475,431.0	7,377,153.0	$426,823

EFFECTS OF CONTROLS FOR STACK 8 FLUX STANDARD = 2
SCENARIO = 1 THICKNESS(in meters) = 2.344

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	550,178.5	698,209.3	$3,227,551
2	550,178.5	698,209.3	$16,873
3	550,178.5	698,209.3	$16,873
4	550,178.5	698,209.3	$16,873
5	550,178.5	698,209.3	$16,873
6	550,178.5	698,209.3	$16,873
7	550,178.5	698,209.3	$16,873
8	550,178.5	698,209.3	$16,873
9	550,178.5	698,209.3	$16,873
10	550,178.5	698,209.3	$16,873
11	550,178.5	698,209.3	$16,873
12	550,178.5	698,209.3	$16,873
13	550,178.5	698,209.3	$16,873
14	550,178.5	698,209.3	$16,873
15	550,178.5	698,209.3	$16,873
16	550,178.5	698,209.3	$16,873
17	550,178.5	698,209.3	$16,873
18	550,178.5	698,209.3	$16,873
19	550,178.5	698,209.3	$16,873
20	550,178.5	698,209.3	$16,873
21	550,178.5	698,209.3	$16,873
22	550,178.5	698,209.3	$16,873
23	550,178.5	698,209.3	$16,873
24	550,178.5	698,209.3	$16,873
25	550,178.5	698,209.3	$16,873
26	550,178.5	698,209.3	$16,873
27	550,178.5	698,209.3	$16,873
28	550,178.5	698,209.3	$16,873
29	550,178.5	698,209.3	$16,873
30	550,178.5	698,209.3	$16,873
31	550,178.5	698,209.3	$16,873
32	550,178.5	698,209.3	$16,873
33	550,178.5	698,209.3	$16,873
34	550,178.5	698,209.3	$16,873
35	550,178.5	698,209.3	$16,873
36	550,178.5	698,209.3	$16,873
37	550,178.5	698,209.3	$16,873
38	550,178.5	698,209.3	$16,873
39	550,178.5	698,209.3	$16,873
40	550,178.5	698,209.3	$16,873
41	550,178.5	698,209.3	$16,873
42	550,178.5	698,209.3	$16,873
43	550,178.5	698,209.3	$16,873
44	550,178.5	698,209.3	$16,873
45	550,178.5	698,209.3	$16,873
46	550,178.5	698,209.3	$16,873
47	550,178.5	698,209.3	$16,873
48	550,178.5	698,209.3	$16,873
49	550,178.5	698,209.3	$16,873
50	550,178.5	698,209.3	$16,873

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 9
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = 1.378

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,200,790.0	841,112.2	$3,703,130
2	1,158,819.0	929,542.9	$49,588
3	1,115,519.0	1,020,773.0	$813,694
4	1,070,704.0	1,115,196.0	$58,680
5	1,024,134.0	1,213,317.0	$877,891
6	975,501.7	1,315,783.0	$69,201
7	924,381.0	1,423,492.0	$964,019
8	486,211.5	2,431,058.0	$5,345,845
9	486,211.5	2,431,058.0	$101,419
10	486,211.5	2,431,058.0	$101,419
11	486,211.5	2,431,058.0	$101,419
12	486,211.5	2,431,058.0	$101,419
13	486,211.5	2,431,058.0	$101,419
14	486,211.5	2,431,058.0	$101,419
15	486,211.5	2,431,058.0	$101,419
16	486,211.5	2,431,058.0	$101,419
17	486,211.5	2,431,058.0	$101,419
18	486,211.5	2,431,058.0	$101,419
19	486,211.5	2,431,058.0	$101,419
20	486,211.5	2,431,058.0	$101,419
21	486,211.5	2,431,058.0	$101,419
22	486,211.5	2,431,058.0	$101,419
23	486,211.5	2,431,058.0	$101,419
24	486,211.5	2,431,058.0	$101,419
25	486,211.5	2,431,058.0	$101,419
26	486,211.5	2,431,058.0	$101,419
27	486,211.5	2,431,058.0	$101,419
28	486,211.5	2,431,058.0	$101,419
29	486,211.5	2,431,058.0	$101,419
30	486,211.5	2,431,058.0	$101,419
31	486,211.5	2,431,058.0	$101,419
32	486,211.5	2,431,058.0	$101,419
33	486,211.5	2,431,058.0	$101,419
34	486,211.5	2,431,058.0	$101,419
35	486,211.5	2,431,058.0	$101,419
36	486,211.5	2,431,058.0	$101,419
37	486,211.5	2,431,058.0	$101,419
38	486,211.5	2,431,058.0	$101,419
39	486,211.5	2,431,058.0	$101,419
40	486,211.5	2,431,058.0	$101,419
41	486,211.5	2,431,058.0	$101,419
42	486,211.5	2,431,058.0	$101,419
43	486,211.5	2,431,058.0	$101,419
44	486,211.5	2,431,058.0	$101,419
45	486,211.5	2,431,058.0	$101,419
46	486,211.5	2,431,058.0	$101,419
47	486,211.5	2,431,058.0	$101,419
48	486,211.5	2,431,058.0	$101,419
49	486,211.5	2,431,058.0	$101,419
50	486,211.5	2,431,058.0	$101,419

EFFECTS OF CONTROLS FOR STACK 10
SCENARIO = 1

FLUX STANDARD = 2
THICKNESS(in meters) = .779

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	86,530.8	432,654.1	$1,617,673
2	86,530.8	432,654.1	$24,004
3	86,530.8	432,654.1	$24,004
4	86,530.8	432,654.1	$24,004
5	86,530.8	432,654.1	$24,004
6	86,530.8	432,654.1	$24,004
7	86,530.8	432,654.1	$24,004
8	86,530.8	432,654.1	$24,004
9	86,530.8	432,654.1	$24,004
10	86,530.8	432,654.1	$24,004
11	86,530.8	432,654.1	$24,004
12	86,530.8	432,654.1	$24,004
13	86,530.8	432,654.1	$24,004
14	86,530.8	432,654.1	$24,004
15	86,530.8	432,654.1	$24,004
16	86,530.8	432,654.1	$24,004
17	86,530.8	432,654.1	$24,004
18	86,530.8	432,654.1	$24,004
19	86,530.8	432,654.1	$24,004
20	86,530.8	432,654.1	$24,004
21	86,530.8	432,654.1	$24,004
22	86,530.8	432,654.1	$24,004
23	86,530.8	432,654.1	$24,004
24	86,530.8	432,654.1	$24,004
25	86,530.8	432,654.1	$24,004
26	86,530.8	432,654.1	$24,004
27	86,530.8	432,654.1	$24,004
28	86,530.8	432,654.1	$24,004
29	86,530.8	432,654.1	$24,004
30	86,530.8	432,654.1	$24,004
31	86,530.8	432,654.1	$24,004
32	86,530.8	432,654.1	$24,004
33	86,530.8	432,654.1	$24,004
34	86,530.8	432,654.1	$24,004
35	86,530.8	432,654.1	$24,004
36	86,530.8	432,654.1	$24,004
37	86,530.8	432,654.1	$24,004
38	86,530.8	432,654.1	$24,004
39	86,530.8	432,654.1	$24,004
40	86,530.8	432,654.1	$24,004
41	86,530.8	432,654.1	$24,004
42	86,530.8	432,654.1	$24,004
43	86,530.8	432,654.1	$24,004
44	86,530.8	432,654.1	$24,004
45	86,530.8	432,654.1	$24,004
46	86,530.8	432,654.1	$24,004
47	86,530.8	432,654.1	$24,004
48	86,530.8	432,654.1	$24,004
49	86,530.8	432,654.1	$24,004
50	86,530.8	432,654.1	$24,004

EFFECTS OF CONTROLS FOR STACK 11 FLUX STANDARD = 2
SCENARIO = 1 THICKNESS(in meters) = .814

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	7,231,534.0	8,165,137.0	$22,308,660
2	6,872,522.0	8,875,178.0	$470,067
3	3,216,295.0	16,081,480.0	$26,294,080
4	3,216,295.0	16,081,480.0	$712,741
5	3,216,295.0	16,081,480.0	$712,741
6	3,216,295.0	16,081,480.0	$712,741
7	3,216,295.0	16,081,480.0	$712,741
8	3,216,295.0	16,081,480.0	$712,741
9	3,216,295.0	16,081,480.0	$712,741
10	3,216,295.0	16,081,480.0	$712,741
11	3,216,295.0	16,081,480.0	$712,741
12	3,216,295.0	16,081,480.0	$712,741
13	3,216,295.0	16,081,480.0	$712,741
14	3,216,295.0	16,081,480.0	$712,741
15	3,216,295.0	16,081,480.0	$712,741
16	3,216,295.0	16,081,480.0	$712,741
17	3,216,295.0	16,081,480.0	$712,741
18	3,216,295.0	16,081,480.0	$712,741
19	3,216,295.0	16,081,480.0	$712,741
20	3,216,295.0	16,081,480.0	$712,741
21	3,216,295.0	16,081,480.0	$712,741
22	3,216,295.0	16,081,480.0	$712,741
23	3,216,295.0	16,081,480.0	$712,741
24	3,216,295.0	16,081,480.0	$712,741
25	3,216,295.0	16,081,480.0	$712,741
26	3,216,295.0	16,081,480.0	$712,741
27	3,216,295.0	16,081,480.0	$712,741
28	3,216,295.0	16,081,480.0	$712,741
29	3,216,295.0	16,081,480.0	$712,741
30	3,216,295.0	16,081,480.0	$712,741
31	3,216,295.0	16,081,480.0	$712,741
32	3,216,295.0	16,081,480.0	$712,741
33	3,216,295.0	16,081,480.0	$712,741
34	3,216,295.0	16,081,480.0	$712,741
35	3,216,295.0	16,081,480.0	$712,741
36	3,216,295.0	16,081,480.0	$712,741
37	3,216,295.0	16,081,480.0	$712,741
38	3,216,295.0	16,081,480.0	$712,741
39	3,216,295.0	16,081,480.0	$712,741
40	3,216,295.0	16,081,480.0	$712,741
41	3,216,295.0	16,081,480.0	$712,741
42	3,216,295.0	16,081,480.0	$712,741
43	3,216,295.0	16,081,480.0	$712,741
44	3,216,295.0	16,081,480.0	$712,741
45	3,216,295.0	16,081,480.0	$712,741
46	3,216,295.0	16,081,480.0	$712,741
47	3,216,295.0	16,081,480.0	$712,741
48	3,216,295.0	16,081,480.0	$712,741
49	3,216,295.0	16,081,480.0	$712,741
50	3,216,295.0	16,081,480.0	$712,741

EFFECTS OF CONTROLS FOR STACK 12 FLUX STANDARD = 2
SCENARIO = 1 THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	476,006.1	1,019,749.0	$3,519,421
2	476,006.1	1,019,749.0	$39,430
3	476,006.1	1,019,749.0	$69,991
4	476,006.1	1,019,749.0	$39,430
5	476,006.1	1,019,749.0	$39,430
6	476,006.1	1,019,749.0	$39,430
7	476,006.1	1,019,749.0	$39,430
8	476,006.1	1,019,749.0	$39,430
9	476,006.1	1,019,749.0	$39,430
10	476,006.1	1,019,749.0	$39,430
11	476,006.1	1,019,749.0	$39,430
12	476,006.1	1,019,749.0	$39,430
13	476,006.1	1,019,749.0	$39,430
14	476,006.1	1,019,749.0	$39,430
15	476,006.1	1,019,749.0	$39,430
16	476,006.1	1,019,749.0	$39,430
17	476,006.1	1,019,749.0	$39,430
18	476,006.1	1,019,749.0	$39,430
19	476,006.1	1,019,749.0	$39,430
20	476,006.1	1,019,749.0	$39,430
21	476,006.1	1,019,749.0	$39,430
22	476,006.1	1,019,749.0	$39,430
23	476,006.1	1,019,749.0	$39,430
24	476,006.1	1,019,749.0	$39,430
25	476,006.1	1,019,749.0	$39,430
26	476,006.1	1,019,749.0	$39,430
27	476,006.1	1,019,749.0	$39,430
28	476,006.1	1,019,749.0	$39,430
29	476,006.1	1,019,749.0	$39,430
30	476,006.1	1,019,749.0	$39,430
31	476,006.1	1,019,749.0	$39,430
32	476,006.1	1,019,749.0	$39,430
33	476,006.1	1,019,749.0	$39,430
34	476,006.1	1,019,749.0	$39,430
35	476,006.1	1,019,749.0	$39,430
36	476,006.1	1,019,749.0	$39,430
37	476,006.1	1,019,749.0	$39,430
38	476,006.1	1,019,749.0	$39,430
39	476,006.1	1,019,749.0	$39,430
40	476,006.1	1,019,749.0	$39,430
41	476,006.1	1,019,749.0	$39,430
42	476,006.1	1,019,749.0	$39,430
43	476,006.1	1,019,749.0	$39,430
44	476,006.1	1,019,749.0	$39,430
45	476,006.1	1,019,749.0	$39,430
46	476,006.1	1,019,749.0	$39,430
47	476,006.1	1,019,749.0	$39,430
48	476,006.1	1,019,749.0	$39,430
49	476,006.1	1,019,749.0	$39,430
50	476,006.1	1,019,749.0	$39,430

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 13 FLUX STANDARD = 2
SCENARIO = 1 THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	814,036.0	1,318,877.0	$4,541,790
2	814,036.0	1,318,877.0	$50,997
3	814,036.0	1,318,877.0	$50,997
4	814,036.0	1,318,877.0	$50,997
5	814,036.0	1,318,877.0	$50,997
6	814,036.0	1,318,877.0	$50,997
7	814,036.0	1,318,877.0	$50,997
8	814,036.0	1,318,877.0	$50,997
9	814,036.0	1,318,877.0	$50,997
10	814,036.0	1,318,877.0	$50,997
11	814,036.0	1,318,877.0	$50,997
12	814,036.0	1,318,877.0	$50,997
13	814,036.0	1,318,877.0	$50,997
14	814,036.0	1,318,877.0	$50,997
15	814,036.0	1,318,877.0	$50,997
16	814,036.0	1,318,877.0	$50,997
17	814,036.0	1,318,877.0	$50,997
18	814,036.0	1,318,877.0	$50,997
19	814,036.0	1,318,877.0	$50,997
20	814,036.0	1,318,877.0	$50,997
21	814,036.0	1,318,877.0	$50,997
22	814,036.0	1,318,877.0	$50,997
23	814,036.0	1,318,877.0	$50,997
24	814,036.0	1,318,877.0	$50,997
25	814,036.0	1,318,877.0	$50,997
26	814,036.0	1,318,877.0	$50,997
27	814,036.0	1,318,877.0	$50,997
28	814,036.0	1,318,877.0	$50,997
29	814,036.0	1,318,877.0	$50,997
30	814,036.0	1,318,877.0	$50,997
31	814,036.0	1,318,877.0	$50,997
32	814,036.0	1,318,877.0	$50,997
33	814,036.0	1,318,877.0	$50,997
34	814,036.0	1,318,877.0	$50,997
35	814,036.0	1,318,877.0	$50,997
36	814,036.0	1,318,877.0	$50,997
37	814,036.0	1,318,877.0	$50,997
38	814,036.0	1,318,877.0	$50,997
39	814,036.0	1,318,877.0	$50,997
40	814,036.0	1,318,877.0	$50,997
41	814,036.0	1,318,877.0	$50,997
42	814,036.0	1,318,877.0	$50,997
43	814,036.0	1,318,877.0	$50,997
44	814,036.0	1,318,877.0	$50,997
45	814,036.0	1,318,877.0	$50,997
46	814,036.0	1,318,877.0	$50,997
47	814,036.0	1,318,877.0	$50,997
48	814,036.0	1,318,877.0	$50,997
49	814,036.0	1,318,877.0	$50,997
50	814,036.0	1,318,877.0	$50,997

EFFECTS OF CONTROLS FOR STACK 14 FLUX STANDARD = 2
SCENARIO = 1 THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,421,334.0	2,146,276.0	$7,385,325
2	737,686.8	3,688,433.0	$6,473,889
3	737,686.8	3,688,433.0	$154,915
4	737,686.8	3,688,433.0	$154,915
5	737,686.8	3,688,433.0	$154,915
6	737,686.8	3,688,433.0	$154,915
7	737,686.8	3,688,433.0	$154,915
8	737,686.8	3,688,433.0	$154,915
9	737,686.8	3,688,433.0	$154,915
10	737,686.8	3,688,433.0	$154,915
11	737,686.8	3,688,433.0	$154,915
12	737,686.8	3,688,433.0	$154,915
13	737,686.8	3,688,433.0	$154,915
14	737,686.8	3,688,433.0	$154,915
15	737,686.8	3,688,433.0	$154,915
16	737,686.8	3,688,433.0	$154,915
17	737,686.8	3,688,433.0	$154,915
18	737,686.8	3,688,433.0	$154,915
19	737,686.8	3,688,433.0	$154,915
20	737,686.8	3,688,433.0	$154,915
21	737,686.8	3,688,433.0	$154,915
22	737,686.8	3,688,433.0	$154,915
23	737,686.8	3,688,433.0	$154,915
24	737,686.8	3,688,433.0	$154,915
25	737,686.8	3,688,433.0	$154,915
26	737,686.8	3,688,433.0	$154,915
27	737,686.8	3,688,433.0	$154,915
28	737,686.8	3,688,433.0	$154,915
29	737,686.8	3,688,433.0	$154,915
30	737,686.8	3,688,433.0	$154,915
31	737,686.8	3,688,433.0	$154,915
32	737,686.8	3,688,433.0	$154,915
33	737,686.8	3,688,433.0	$154,915
34	737,686.8	3,688,433.0	$154,915
35	737,686.8	3,688,433.0	$154,915
36	737,686.8	3,688,433.0	$154,915
37	737,686.8	3,688,433.0	$154,915
38	737,686.8	3,688,433.0	$154,915
39	737,686.8	3,688,433.0	$154,915
40	737,686.8	3,688,433.0	$154,915
41	737,686.8	3,688,433.0	$154,915
42	737,686.8	3,688,433.0	$154,915
43	737,686.8	3,688,433.0	$154,915
44	737,686.8	3,688,433.0	$154,915
45	737,686.8	3,688,433.0	$154,915
46	737,686.8	3,688,433.0	$154,915
47	737,686.8	3,688,433.0	$154,915
48	737,686.8	3,688,433.0	$154,915
49	737,686.8	3,688,433.0	$154,915
50	737,686.8	3,688,433.0	$154,915

EFFECTS OF CONTROLS FOR STACK 5 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = .995

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	6,895,139.0	0.0	$0
2	6,976,675.0	0.0	$0
3	7,059,347.0	0.0	$0
4	7,143,211.0	0.0	$0
5	7,228,350.0	0.0	$0
6	7,314,824.0	0.0	$0
7	7,402,742.0	0.0	$0
8	7,492,196.0	0.0	$0
9	7,583,303.0	0.0	$0
10	7,676,186.0	0.0	$0
11	7,771,001.0	0.0	$0
12	7,867,916.0	0.0	$0
13	7,967,126.0	0.0	$0
14	8,068,868.0	0.0	$0
15	1,658,091.0	8,290,455.0	$30,299,880
16	1,658,091.0	8,290,455.0	$357,865
17	1,658,091.0	8,290,455.0	$357,865
18	1,658,091.0	8,290,455.0	$357,865
19	1,658,091.0	8,290,455.0	$357,865
20	1,658,091.0	8,290,455.0	$357,865
21	1,658,091.0	8,290,455.0	$357,865
22	1,658,091.0	8,290,455.0	$357,865
23	1,658,091.0	8,290,455.0	$357,865
24	1,658,091.0	8,290,455.0	$357,865
25	1,658,091.0	8,290,455.0	$357,865
26	1,658,091.0	8,290,455.0	$357,865
27	1,658,091.0	8,290,455.0	$357,865
28	1,658,091.0	8,290,455.0	$357,865
29	1,658,091.0	8,290,455.0	$357,865
30	1,658,091.0	8,290,455.0	$357,865
31	1,658,091.0	8,290,455.0	$357,865
32	1,658,091.0	8,290,455.0	$357,865
33	1,658,091.0	8,290,455.0	$357,865
34	1,658,091.0	8,290,455.0	$357,865
35	1,658,091.0	8,290,455.0	$357,865
36	1,658,091.0	8,290,455.0	$357,865
37	1,658,091.0	8,290,455.0	$357,865
38	1,658,091.0	8,290,455.0	$357,865
39	1,658,091.0	8,290,455.0	$357,865
40	1,658,091.0	8,290,455.0	$357,865
41	1,658,091.0	8,290,455.0	$357,865
42	1,658,091.0	8,290,455.0	$357,865
43	1,658,091.0	8,290,455.0	$357,865
44	1,658,091.0	8,290,455.0	$357,865
45	1,658,091.0	8,290,455.0	$357,865
46	1,658,091.0	8,290,455.0	$357,865
47	1,658,091.0	8,290,455.0	$357,865
48	1,658,091.0	8,290,455.0	$357,865
49	1,658,091.0	8,290,455.0	$357,865
50	1,658,091.0	8,290,455.0	$357,865

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 6 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	8,345,288.0	0.0	$0
2	1,627,573.0	8,137,861.0	$38,486,910
3	1,627,573.0	8,137,861.0	$433,433
4	1,627,573.0	8,137,861.0	$433,433
5	1,627,573.0	8,137,861.0	$433,433
6	1,627,573.0	8,137,861.0	$433,433
7	1,627,573.0	8,137,861.0	$433,433
8	1,627,573.0	8,137,861.0	$433,433
9	1,627,573.0	8,137,861.0	$433,433
10	1,627,573.0	8,137,861.0	$433,433
11	1,627,573.0	8,137,861.0	$433,433
12	1,627,573.0	8,137,861.0	$433,433
13	1,627,573.0	8,137,861.0	$433,433
14	1,627,573.0	8,137,861.0	$433,433
15	1,627,573.0	8,137,861.0	$433,433
16	1,627,573.0	8,137,861.0	$433,433
17	1,627,573.0	8,137,861.0	$433,433
18	1,627,573.0	8,137,861.0	$433,433
19	1,627,573.0	8,137,861.0	$433,433
20	1,627,573.0	8,137,861.0	$433,433
21	1,627,573.0	8,137,861.0	$433,433
22	1,627,573.0	8,137,861.0	$433,433
23	1,627,573.0	8,137,861.0	$433,433
24	1,627,573.0	8,137,861.0	$433,433
25	1,627,573.0	8,137,861.0	$433,433
26	1,627,573.0	8,137,861.0	$433,433
27	1,627,573.0	8,137,861.0	$433,433
28	1,627,573.0	8,137,861.0	$433,433
29	1,627,573.0	8,137,861.0	$433,433
30	1,627,573.0	8,137,861.0	$433,433
31	1,627,573.0	8,137,861.0	$433,433
32	1,627,573.0	8,137,861.0	$433,433
33	1,627,573.0	8,137,861.0	$433,433
34	1,627,573.0	8,137,861.0	$433,433
35	1,627,573.0	8,137,861.0	$433,433
36	1,627,573.0	8,137,861.0	$433,433
37	1,627,573.0	8,137,861.0	$433,433
38	1,627,573.0	8,137,861.0	$433,433
39	1,627,573.0	8,137,861.0	$433,433
40	1,627,573.0	8,137,861.0	$433,433
41	1,627,573.0	8,137,861.0	$433,433
42	1,627,573.0	8,137,861.0	$433,433
43	1,627,573.0	8,137,861.0	$433,433
44	1,627,573.0	8,137,861.0	$433,433
45	1,627,573.0	8,137,861.0	$433,433
46	1,627,573.0	8,137,861.0	$433,433
47	1,627,573.0	8,137,861.0	$433,433
48	1,627,573.0	8,137,861.0	$433,433
49	1,627,573.0	8,137,861.0	$433,433
50	1,627,573.0	8,137,861.0	$433,433

EFFECTS OF CONTROLS FOR STACK 7 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,475,431.0	7,377,153.0	$37,895,730
2	1,475,431.0	7,377,153.0	$426,823
3	1,475,431.0	7,377,153.0	$426,823
4	1,475,431.0	7,377,153.0	$426,823
5	1,475,431.0	7,377,153.0	$426,823
6	1,475,431.0	7,377,153.0	$426,823
7	1,475,431.0	7,377,153.0	$426,823
8	1,475,431.0	7,377,153.0	$426,823
9	1,475,431.0	7,377,153.0	$426,823
10	1,475,431.0	7,377,153.0	$426,823
11	1,475,431.0	7,377,153.0	$426,823
12	1,475,431.0	7,377,153.0	$426,823
13	1,475,431.0	7,377,153.0	$426,823
14	1,475,431.0	7,377,153.0	$426,823
15	1,475,431.0	7,377,153.0	$426,823
16	1,475,431.0	7,377,153.0	$426,823
17	1,475,431.0	7,377,153.0	$426,823
18	1,475,431.0	7,377,153.0	$426,823
19	1,475,431.0	7,377,153.0	$426,823
20	1,475,431.0	7,377,153.0	$426,823
21	1,475,431.0	7,377,153.0	$426,823
22	1,475,431.0	7,377,153.0	$426,823
23	1,475,431.0	7,377,153.0	$426,823
24	1,475,431.0	7,377,153.0	$426,823
25	1,475,431.0	7,377,153.0	$426,823
26	1,475,431.0	7,377,153.0	$426,823
27	1,475,431.0	7,377,153.0	$426,823
28	1,475,431.0	7,377,153.0	$426,823
29	1,475,431.0	7,377,153.0	$426,823
30	1,475,431.0	7,377,153.0	$426,823
31	1,475,431.0	7,377,153.0	$426,823
32	1,475,431.0	7,377,153.0	$426,823
33	1,475,431.0	7,377,153.0	$426,823
34	1,475,431.0	7,377,153.0	$426,823
35	1,475,431.0	7,377,153.0	$426,823
36	1,475,431.0	7,377,153.0	$426,823
37	1,475,431.0	7,377,153.0	$426,823
38	1,475,431.0	7,377,153.0	$426,823
39	1,475,431.0	7,377,153.0	$426,823
40	1,475,431.0	7,377,153.0	$426,823
41	1,475,431.0	7,377,153.0	$426,823
42	1,475,431.0	7,377,153.0	$426,823
43	1,475,431.0	7,377,153.0	$426,823
44	1,475,431.0	7,377,153.0	$426,823
45	1,475,431.0	7,377,153.0	$426,823
46	1,475,431.0	7,377,153.0	$426,823
47	1,475,431.0	7,377,153.0	$426,823
48	1,475,431.0	7,377,153.0	$426,823
49	1,475,431.0	7,377,153.0	$426,823
50	1,475,431.0	7,377,153.0	$426,823

EFFECTS OF CONTROLS FOR STACK 8
SCENARIO = 2

FLUX STANDARD = 2
THICKNESS(in meters) = 2.344

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,248,388.0	0.0	$0
2	1,248,388.0	0.0	$0
3	1,248,388.0	0.0	$0
4	1,248,388.0	0.0	$0
5	1,248,388.0	0.0	$0
6	1,248,388.0	0.0	$0
7	1,248,388.0	0.0	$0
8	1,248,388.0	0.0	$0
9	1,248,388.0	0.0	$0
10	1,248,388.0	0.0	$0
11	1,248,388.0	0.0	$0
12	1,248,388.0	0.0	$0
13	1,248,388.0	0.0	$0
14	1,248,388.0	0.0	$0
15	1,248,388.0	0.0	$0
16	1,248,388.0	0.0	$0
17	1,248,388.0	0.0	$0
18	1,248,388.0	0.0	$0
19	1,248,388.0	0.0	$0
20	1,248,388.0	0.0	$0
21	1,248,388.0	0.0	$0
22	1,248,388.0	0.0	$0
23	1,248,388.0	0.0	$0
24	1,248,388.0	0.0	$0
25	1,248,388.0	0.0	$0
26	1,248,388.0	0.0	$0
27	1,248,388.0	0.0	$0
28	1,248,388.0	0.0	$0
29	1,248,388.0	0.0	$0
30	1,248,388.0	0.0	$0
31	1,248,388.0	0.0	$0
32	1,248,388.0	0.0	$0
33	1,248,388.0	0.0	$0
34	1,248,388.0	0.0	$0
35	1,248,388.0	0.0	$0
36	1,248,388.0	0.0	$0
37	1,248,388.0	0.0	$0
38	1,248,388.0	0.0	$0
39	1,248,388.0	0.0	$0
40	1,248,388.0	0.0	$0
41	1,248,388.0	0.0	$0
42	1,248,388.0	0.0	$0
43	1,248,388.0	0.0	$0
44	1,248,388.0	0.0	$0
45	1,248,388.0	0.0	$0
46	1,248,388.0	0.0	$0
47	1,248,388.0	0.0	$0
48	1,248,388.0	0.0	$0
49	1,248,388.0	0.0	$0
50	1,248,388.0	0.0	$0

EFFECTS OF CONTROLS FOR STACK 9
SCENARIO = 2

FLUX STANDARD = 2
THICKNESS(in meters) = 1.378

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	2,041,902.0	0.0	$0
2	2,088,362.0	0.0	$0
3	2,136,292.0	0.0	$0
4	2,185,900.0	0.0	$0
5	2,237,451.0	0.0	$0
6	2,291,285.0	0.0	$0
7	2,347,873.0	0.0	$0
8	486,211.5	2,431,058.0	$11,578,160
9	486,211.5	2,431,058.0	$101,419
10	486,211.5	2,431,058.0	$101,419
11	486,211.5	2,431,058.0	$101,419
12	486,211.5	2,431,058.0	$101,419
13	486,211.5	2,431,058.0	$101,419
14	486,211.5	2,431,058.0	$101,419
15	486,211.5	2,431,058.0	$101,419
16	486,211.5	2,431,058.0	$101,419
17	486,211.5	2,431,058.0	$101,419
18	486,211.5	2,431,058.0	$101,419
19	486,211.5	2,431,058.0	$101,419
20	486,211.5	2,431,058.0	$101,419
21	486,211.5	2,431,058.0	$101,419
22	486,211.5	2,431,058.0	$101,419
23	486,211.5	2,431,058.0	$101,419
24	486,211.5	2,431,058.0	$101,419
25	486,211.5	2,431,058.0	$101,419
26	486,211.5	2,431,058.0	$101,419
27	486,211.5	2,431,058.0	$101,419
28	486,211.5	2,431,058.0	$101,419
29	486,211.5	2,431,058.0	$101,419
30	486,211.5	2,431,058.0	$101,419
31	486,211.5	2,431,058.0	$101,419
32	486,211.5	2,431,058.0	$101,419
33	486,211.5	2,431,058.0	$101,419
34	486,211.5	2,431,058.0	$101,419
35	486,211.5	2,431,058.0	$101,419
36	486,211.5	2,431,058.0	$101,419
37	486,211.5	2,431,058.0	$101,419
38	486,211.5	2,431,058.0	$101,419
39	486,211.5	2,431,058.0	$101,419
40	486,211.5	2,431,058.0	$101,419
41	486,211.5	2,431,058.0	$101,419
42	486,211.5	2,431,058.0	$101,419
43	486,211.5	2,431,058.0	$101,419
44	486,211.5	2,431,058.0	$101,419
45	486,211.5	2,431,058.0	$101,419
46	486,211.5	2,431,058.0	$101,419
47	486,211.5	2,431,058.0	$101,419
48	486,211.5	2,431,058.0	$101,419
49	486,211.5	2,431,058.0	$101,419
50	486,211.5	2,431,058.0	$101,419

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 10 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = .779

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	86,530.8	432,654.1	$1,617,673
2	86,530.8	432,654.1	$24,004
3	86,530.8	432,654.1	$24,004
4	86,530.8	432,654.1	$24,004
5	86,530.8	432,654.1	$24,004
6	86,530.8	432,654.1	$24,004
7	86,530.8	432,654.1	$24,004
8	86,530.8	432,654.1	$24,004
9	86,530.8	432,654.1	$24,004
10	86,530.8	432,654.1	$24,004
11	86,530.8	432,654.1	$24,004
12	86,530.8	432,654.1	$24,004
13	86,530.8	432,654.1	$24,004
14	86,530.8	432,654.1	$24,004
15	86,530.8	432,654.1	$24,004
16	86,530.8	432,654.1	$24,004
17	86,530.8	432,654.1	$24,004
18	86,530.8	432,654.1	$24,004
19	86,530.8	432,654.1	$24,004
20	86,530.8	432,654.1	$24,004
21	86,530.8	432,654.1	$24,004
22	86,530.8	432,654.1	$24,004
23	86,530.8	432,654.1	$24,004
24	86,530.8	432,654.1	$24,004
25	86,530.8	432,654.1	$24,004
26	86,530.8	432,654.1	$24,004
27	86,530.8	432,654.1	$24,004
28	86,530.8	432,654.1	$24,004
29	86,530.8	432,654.1	$24,004
30	86,530.8	432,654.1	$24,004
31	86,530.8	432,654.1	$24,004
32	86,530.8	432,654.1	$24,004
33	86,530.8	432,654.1	$24,004
34	86,530.8	432,654.1	$24,004
35	86,530.8	432,654.1	$24,004
36	86,530.8	432,654.1	$24,004
37	86,530.8	432,654.1	$24,004
38	86,530.8	432,654.1	$24,004
39	86,530.8	432,654.1	$24,004
40	86,530.8	432,654.1	$24,004
41	86,530.8	432,654.1	$24,004
42	86,530.8	432,654.1	$24,004
43	86,530.8	432,654.1	$24,004
44	86,530.8	432,654.1	$24,004
45	86,530.8	432,654.1	$24,004
46	86,530.8	432,654.1	$24,004
47	86,530.8	432,654.1	$24,004
48	86,530.8	432,654.1	$24,004
49	86,530.8	432,654.1	$24,004
50	86,530.8	432,654.1	$24,004

EFFECTS OF CONTROLS FOR STACK 12 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,495,756.0	0.0	$0
2	1,495,756.0	0.0	$0
3	1,495,756.0	0.0	$0
4	1,495,756.0	0.0	$0
5	1,495,756.0	0.0	$0
6	1,495,756.0	0.0	$0
7	1,495,756.0	0.0	$0
8	1,495,756.0	0.0	$0
9	1,495,756.0	0.0	$0
10	1,495,756.0	0.0	$0
11	1,495,756.0	0.0	$0
12	1,495,756.0	0.0	$0
13	1,495,756.0	0.0	$0
14	1,495,756.0	0.0	$0
15	1,495,756.0	0.0	$0
16	1,495,756.0	0.0	$0
17	1,495,756.0	0.0	$0
18	1,495,756.0	0.0	$0
19	1,495,756.0	0.0	$0
20	1,495,756.0	0.0	$0
21	1,495,756.0	0.0	$0
22	1,495,756.0	0.0	$0
23	1,495,756.0	0.0	$0
24	1,495,756.0	0.0	$0
25	1,495,756.0	0.0	$0
26	1,495,756.0	0.0	$0
27	1,495,756.0	0.0	$0
28	1,495,756.0	0.0	$0
29	1,495,756.0	0.0	$0
30	1,495,756.0	0.0	$0
31	1,495,756.0	0.0	$0
32	1,495,756.0	0.0	$0
33	1,495,756.0	0.0	$0
34	1,495,756.0	0.0	$0
35	1,495,756.0	0.0	$0
36	1,495,756.0	0.0	$0
37	1,495,756.0	0.0	$0
38	1,495,756.0	0.0	$0
39	1,495,756.0	0.0	$0
40	1,495,756.0	0.0	$0
41	1,495,756.0	0.0	$0
42	1,495,756.0	0.0	$0
43	1,495,756.0	0.0	$0
44	1,495,756.0	0.0	$0
45	1,495,756.0	0.0	$0
46	1,495,756.0	0.0	$0
47	1,495,756.0	0.0	$0
48	1,495,756.0	0.0	$0
49	1,495,756.0	0.0	$0
50	1,495,756.0	0.0	$0

EFFECTS OF CONTROLS FOR STACK 11 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = .814

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	15,396,670.0	0.0	$0
2	15,747,700.0	0.0	$0
3	3,216,295.0	16,081,480.0	$50,212,090
4	3,216,295.0	16,081,480.0	$712,741
5	3,216,295.0	16,081,480.0	$712,741
6	3,216,295.0	16,081,480.0	$712,741
7	3,216,295.0	16,081,480.0	$712,741
8	3,216,295.0	16,081,480.0	$712,741
9	3,216,295.0	16,081,480.0	$712,741
10	3,216,295.0	16,081,480.0	$712,741
11	3,216,295.0	16,081,480.0	$712,741
12	3,216,295.0	16,081,480.0	$712,741
13	3,216,295.0	16,081,480.0	$712,741
14	3,216,295.0	16,081,480.0	$712,741
15	3,216,295.0	16,081,480.0	$712,741
16	3,216,295.0	16,081,480.0	$712,741
17	3,216,295.0	16,081,480.0	$712,741
18	3,216,295.0	16,081,480.0	$712,741
19	3,216,295.0	16,081,480.0	$712,741
20	3,216,295.0	16,081,480.0	$712,741
21	3,216,295.0	16,081,480.0	$712,741
22	3,216,295.0	16,081,480.0	$712,741
23	3,216,295.0	16,081,480.0	$712,741
24	3,216,295.0	16,081,480.0	$712,741
25	3,216,295.0	16,081,480.0	$712,741
26	3,216,295.0	16,081,480.0	$712,741
27	3,216,295.0	16,081,480.0	$712,741
28	3,216,295.0	16,081,480.0	$712,741
29	3,216,295.0	16,081,480.0	$712,741
30	3,216,295.0	16,081,480.0	$712,741
31	3,216,295.0	16,081,480.0	$712,741
32	3,216,295.0	16,081,480.0	$712,741
33	3,216,295.0	16,081,480.0	$712,741
34	3,216,295.0	16,081,480.0	$712,741
35	3,216,295.0	16,081,480.0	$712,741
36	3,216,295.0	16,081,480.0	$712,741
37	3,216,295.0	16,081,480.0	$712,741
38	3,216,295.0	16,081,480.0	$712,741
39	3,216,295.0	16,081,480.0	$712,741
40	3,216,295.0	16,081,480.0	$712,741
41	3,216,295.0	16,081,480.0	$712,741
42	3,216,295.0	16,081,480.0	$712,741
43	3,216,295.0	16,081,480.0	$712,741
44	3,216,295.0	16,081,480.0	$712,741
45	3,216,295.0	16,081,480.0	$712,741
46	3,216,295.0	16,081,480.0	$712,741
47	3,216,295.0	16,081,480.0	$712,741
48	3,216,295.0	16,081,480.0	$712,741
49	3,216,295.0	16,081,480.0	$712,741
50	3,216,295.0	16,081,480.0	$712,741

EFFECTS OF CONTROLS FOR STACK 13 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	2,132,913.0	0.0	$0
2	2,132,913.0	0.0	$0
3	2,132,913.0	0.0	$0
4	2,132,913.0	0.0	$0
5	2,132,913.0	0.0	$0
6	2,132,913.0	0.0	$0
7	2,132,913.0	0.0	$0
8	2,132,913.0	0.0	$0
9	2,132,913.0	0.0	$0
10	2,132,913.0	0.0	$0
11	2,132,913.0	0.0	$0
12	2,132,913.0	0.0	$0
13	2,132,913.0	0.0	$0
14	2,132,913.0	0.0	$0
15	2,132,913.0	0.0	$0
16	2,132,913.0	0.0	$0
17	2,132,913.0	0.0	$0
18	2,132,913.0	0.0	$0
19	2,132,913.0	0.0	$0
20	2,132,913.0	0.0	$0
21	2,132,913.0	0.0	$0
22	2,132,913.0	0.0	$0
23	2,132,913.0	0.0	$0
24	2,132,913.0	0.0	$0
25	2,132,913.0	0.0	$0
26	2,132,913.0	0.0	$0
27	2,132,913.0	0.0	$0
28	2,132,913.0	0.0	$0
29	2,132,913.0	0.0	$0
30	2,132,913.0	0.0	$0
31	2,132,913.0	0.0	$0
32	2,132,913.0	0.0	$0
33	2,132,913.0	0.0	$0
34	2,132,913.0	0.0	$0
35	2,132,913.0	0.0	$0
36	2,132,913.0	0.0	$0
37	2,132,913.0	0.0	$0
38	2,132,913.0	0.0	$0
39	2,132,913.0	0.0	$0
40	2,132,913.0	0.0	$0
41	2,132,913.0	0.0	$0
42	2,132,913.0	0.0	$0
43	2,132,913.0	0.0	$0
44	2,132,913.0	0.0	$0
45	2,132,913.0	0.0	$0
46	2,132,913.0	0.0	$0
47	2,132,913.0	0.0	$0
48	2,132,913.0	0.0	$0
49	2,132,913.0	0.0	$0
50	2,132,913.0	0.0	$0

EFFECTS OF CONTROLS FOR STACK 14
SCENARIO = 2

FLUX STANDARD = 2
THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	3,567,610.0	0.0	$0
2	737,686.8	3,688,433.0	$13,776,220
3	737,686.8	3,688,433.0	$154,915
4	737,686.8	3,688,433.0	$154,915
5	737,686.8	3,688,433.0	$154,915
6	737,686.8	3,688,433.0	$154,915
7	737,686.8	3,688,433.0	$154,915
8	737,686.8	3,688,433.0	$154,915
9	737,686.8	3,688,433.0	$154,915
10	737,686.8	3,688,433.0	$154,915
11	737,686.8	3,688,433.0	$154,915
12	737,686.8	3,688,433.0	$154,915
13	737,686.8	3,688,433.0	$154,915
14	737,686.8	3,688,433.0	$154,915
15	737,686.8	3,688,433.0	$154,915
16	737,686.8	3,688,433.0	$154,915
17	737,686.8	3,688,433.0	$154,915
18	737,686.8	3,688,433.0	$154,915
19	737,686.8	3,688,433.0	$154,915
20	737,686.8	3,688,433.0	$154,915
21	737,686.8	3,688,433.0	$154,915
22	737,686.8	3,688,433.0	$154,915
23	737,686.8	3,688,433.0	$154,915
24	737,686.8	3,688,433.0	$154,915
25	737,686.8	3,688,433.0	$154,915
26	737,686.8	3,688,433.0	$154,915
27	737,686.8	3,688,433.0	$154,915
28	737,686.8	3,688,433.0	$154,915
29	737,686.8	3,688,433.0	$154,915
30	737,686.8	3,688,433.0	$154,915
31	737,686.8	3,688,433.0	$154,915
32	737,686.8	3,688,433.0	$154,915
33	737,686.8	3,688,433.0	$154,915
34	737,686.8	3,688,433.0	$154,915
35	737,686.8	3,688,433.0	$154,915
36	737,686.8	3,688,433.0	$154,915
37	737,686.8	3,688,433.0	$154,915
38	737,686.8	3,688,433.0	$154,915
39	737,686.8	3,688,433.0	$154,915
40	737,686.8	3,688,433.0	$154,915
41	737,686.8	3,688,433.0	$154,915
42	737,686.8	3,688,433.0	$154,915
43	737,686.8	3,688,433.0	$154,915
44	737,686.8	3,688,433.0	$154,915
45	737,686.8	3,688,433.0	$154,915
46	737,686.8	3,688,433.0	$154,915
47	737,686.8	3,688,433.0	$154,915
48	737,686.8	3,688,433.0	$154,915
49	737,686.8	3,688,433.0	$154,915
50	737,686.8	3,688,433.0	$154,915

EFFECTS OF CONTROLS FOR STACK 1
SCENARIO = 1

FLUX STANDARD = 6
THICKNESS(in meters) = .385

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,141,693.0	790,472.8	$1,897,691
2	1,229,574.0	1,229,574.0	$988,475
3	1,229,574.0	1,229,574.0	$111,128
4	1,229,574.0	1,229,574.0	$76,405
5	1,229,574.0	1,229,574.0	$76,405
6	1,229,574.0	1,229,574.0	$76,405
7	1,229,574.0	1,229,574.0	$76,405
8	1,229,574.0	1,229,574.0	$76,405
9	1,229,574.0	1,229,574.0	$76,405
10	1,229,574.0	1,229,574.0	$76,405
11	1,229,574.0	1,229,574.0	$76,405
12	1,229,574.0	1,229,574.0	$76,405
13	1,229,574.0	1,229,574.0	$76,405
14	1,229,574.0	1,229,574.0	$76,405
15	1,229,574.0	1,229,574.0	$76,405
16	1,229,574.0	1,229,574.0	$76,405
17	1,229,574.0	1,229,574.0	$76,405
18	1,229,574.0	1,229,574.0	$76,405
19	1,229,574.0	1,229,574.0	$76,405
20	1,229,574.0	1,229,574.0	$76,405
21	1,229,574.0	1,229,574.0	$76,405
22	1,229,574.0	1,229,574.0	$76,405
23	1,229,574.0	1,229,574.0	$76,405
24	1,229,574.0	1,229,574.0	$76,405
25	1,229,574.0	1,229,574.0	$76,405
26	1,229,574.0	1,229,574.0	$76,405
27	1,229,574.0	1,229,574.0	$76,405
28	1,229,574.0	1,229,574.0	$76,405
29	1,229,574.0	1,229,574.0	$76,405
30	1,229,574.0	1,229,574.0	$76,405
31	1,229,574.0	1,229,574.0	$76,405
32	1,229,574.0	1,229,574.0	$76,405
33	1,229,574.0	1,229,574.0	$76,405
34	1,229,574.0	1,229,574.0	$76,405
35	1,229,574.0	1,229,574.0	$76,405
36	1,229,574.0	1,229,574.0	$76,405
37	1,229,574.0	1,229,574.0	$76,405
38	1,229,574.0	1,229,574.0	$76,405
39	1,229,574.0	1,229,574.0	$76,405
40	1,229,574.0	1,229,574.0	$76,405
41	1,229,574.0	1,229,574.0	$76,405
42	1,229,574.0	1,229,574.0	$76,405
43	1,229,574.0	1,229,574.0	$76,405
44	1,229,574.0	1,229,574.0	$76,405
45	1,229,574.0	1,229,574.0	$76,405
46	1,229,574.0	1,229,574.0	$76,405
47	1,229,574.0	1,229,574.0	$76,405
48	1,229,574.0	1,229,574.0	$76,405
49	1,229,574.0	1,229,574.0	$76,405
50	1,229,574.0	1,229,574.0	$76,405

EFFECTS OF CONTROLS FOR STACK 2
SCENARIO = 1

FLUX STANDARD = 6
THICKNESS(in meters) = .385

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,235,009.0	361,758.9	$852,614
2	1,229,134.0	409,002.3	$91,304
3	1,223,062.0	457,827.8	$240,901
4	1,216,763.0	508,474.0	$46,429
5	1,210,200.0	561,244.8	$264,900
6	1,203,322.0	616,552.8	$56,025
7	1,196,057.0	674,966.1	$296,885
8	1,160,500.0	1,160,501.0	$1,434,479
9	1,160,500.0	1,160,501.0	$81,277
10	1,160,500.0	1,160,501.0	$81,277
11	1,160,500.0	1,160,501.0	$81,277
12	1,160,500.0	1,160,501.0	$81,277
13	1,160,500.0	1,160,501.0	$81,277
14	1,160,500.0	1,160,501.0	$81,277
15	1,160,500.0	1,160,501.0	$81,277
16	1,160,500.0	1,160,501.0	$81,277
17	1,160,500.0	1,160,501.0	$81,277
18	1,160,500.0	1,160,501.0	$81,277
19	1,160,500.0	1,160,501.0	$81,277
20	1,160,500.0	1,160,501.0	$81,277
21	1,160,500.0	1,160,501.0	$81,277
22	1,160,500.0	1,160,501.0	$81,277
23	1,160,500.0	1,160,501.0	$81,277
24	1,160,500.0	1,160,501.0	$81,277
25	1,160,500.0	1,160,501.0	$81,277
26	1,160,500.0	1,160,501.0	$81,277
27	1,160,500.0	1,160,501.0	$81,277
28	1,160,500.0	1,160,501.0	$81,277
29	1,160,500.0	1,160,501.0	$81,277
30	1,160,500.0	1,160,501.0	$81,277
31	1,160,500.0	1,160,501.0	$81,277
32	1,160,500.0	1,160,501.0	$81,277
33	1,160,500.0	1,160,501.0	$81,277
34	1,160,500.0	1,160,501.0	$81,277
35	1,160,500.0	1,160,501.0	$81,277
36	1,160,500.0	1,160,501.0	$81,277
37	1,160,500.0	1,160,501.0	$81,277
38	1,160,500.0	1,160,501.0	$81,277
39	1,160,500.0	1,160,501.0	$81,277
40	1,160,500.0	1,160,501.0	$81,277
41	1,160,500.0	1,160,501.0	$81,277
42	1,160,500.0	1,160,501.0	$81,277
43	1,160,500.0	1,160,501.0	$81,277
44	1,160,500.0	1,160,501.0	$81,277
45	1,160,500.0	1,160,501.0	$81,277
46	1,160,500.0	1,160,501.0	$81,277
47	1,160,500.0	1,160,501.0	$81,277
48	1,160,500.0	1,160,501.0	$81,277
49	1,160,500.0	1,160,501.0	$81,277
50	1,160,500.0	1,160,501.0	$81,277

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 3 FLUX STANDARD = 6
SCENARIO = 1 THICKNESS(in meters) = .333

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	354,356.6	291,323.3	$4,635,814
2	354,356.6	291,323.3	$141,610
3	354,356.6	291,323.3	$141,610
4	354,356.6	291,323.3	$141,610
5	354,356.6	291,323.3	$141,610
6	354,356.6	291,323.3	$141,610
7	354,356.6	291,323.3	$141,610
8	354,356.6	291,323.3	$141,610
9	354,356.6	291,323.3	$141,610
10	354,356.6	291,323.3	$141,610
11	354,356.6	291,323.3	$141,610
12	354,356.6	291,323.3	$141,610
13	354,356.6	291,323.3	$141,610
14	354,356.6	291,323.3	$141,610
15	354,356.6	291,323.3	$141,610
16	354,356.6	291,323.3	$141,610
17	354,356.6	291,323.3	$141,610
18	354,356.6	291,323.3	$141,610
19	354,356.6	291,323.3	$141,610
20	354,356.6	291,323.3	$141,610
21	354,356.6	291,323.3	$141,610
22	354,356.6	291,323.3	$141,610
23	354,356.6	291,323.3	$141,610
24	354,356.6	291,323.3	$141,610
25	354,356.6	291,323.3	$141,610
26	354,356.6	291,323.3	$141,610
27	354,356.6	291,323.3	$141,610
28	354,356.6	291,323.3	$141,610
29	354,356.6	291,323.3	$141,610
30	354,356.6	291,323.3	$141,610
31	354,356.6	291,323.3	$141,610
32	354,356.6	291,323.3	$141,610
33	354,356.6	291,323.3	$141,610
34	354,356.6	291,323.3	$141,610
35	354,356.6	291,323.3	$141,610
36	354,356.6	291,323.3	$141,610
37	354,356.6	291,323.3	$141,610
38	354,356.6	291,323.3	$141,610
39	354,356.6	291,323.3	$141,610
40	354,356.6	291,323.3	$141,610
41	354,356.6	291,323.3	$141,610
42	354,356.6	291,323.3	$141,610
43	354,356.6	291,323.3	$141,610
44	354,356.6	291,323.3	$141,610
45	354,356.6	291,323.3	$141,610
46	354,356.6	291,323.3	$141,610
47	354,356.6	291,323.3	$141,610
48	354,356.6	291,323.3	$141,610
49	354,356.6	291,323.3	$141,610
50	354,356.6	291,323.3	$141,610

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 4
SCENARIO = 1

FLUX STANDARD = 6
THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	3,528,548.0	1,217,779.0	$3,103,321
2	2,779,089.0	2,779,090.0	$6,541,975
3	2,779,089.0	2,779,090.0	$246,010
4	2,779,089.0	2,779,090.0	$246,010
5	2,779,089.0	2,779,090.0	$246,010
6	2,779,089.0	2,779,090.0	$246,010
7	2,779,089.0	2,779,090.0	$246,010
8	2,779,089.0	2,779,090.0	$246,010
9	2,779,089.0	2,779,090.0	$246,010
10	2,779,089.0	2,779,090.0	$246,010
11	2,779,089.0	2,779,090.0	$246,010
12	2,779,089.0	2,779,090.0	$246,010
13	2,779,089.0	2,779,090.0	$246,010
14	2,779,089.0	2,779,090.0	$246,010
15	2,779,089.0	2,779,090.0	$246,010
16	2,779,089.0	2,779,090.0	$246,010
17	2,779,089.0	2,779,090.0	$246,010
18	2,779,089.0	2,779,090.0	$246,010
19	2,779,089.0	2,779,090.0	$246,010
20	2,779,089.0	2,779,090.0	$246,010
21	2,779,089.0	2,779,090.0	$246,010
22	2,779,089.0	2,779,090.0	$246,010
23	2,779,089.0	2,779,090.0	$246,010
24	2,779,089.0	2,779,090.0	$246,010
25	2,779,089.0	2,779,090.0	$246,010
26	2,779,089.0	2,779,090.0	$246,010
27	2,779,089.0	2,779,090.0	$246,010
28	2,779,089.0	2,779,090.0	$246,010
29	2,779,089.0	2,779,090.0	$246,010
30	2,779,089.0	2,779,090.0	$246,010
31	2,779,089.0	2,779,090.0	$246,010
32	2,779,089.0	2,779,090.0	$246,010
33	2,779,089.0	2,779,090.0	$246,010
34	2,779,089.0	2,779,090.0	$246,010
35	2,779,089.0	2,779,090.0	$246,010
36	2,779,089.0	2,779,090.0	$246,010
37	2,779,089.0	2,779,090.0	$246,010
38	2,779,089.0	2,779,090.0	$246,010
39	2,779,089.0	2,779,090.0	$246,010
40	2,779,089.0	2,779,090.0	$246,010
41	2,779,089.0	2,779,090.0	$246,010
42	2,779,089.0	2,779,090.0	$246,010
43	2,779,089.0	2,779,090.0	$246,010
44	2,779,089.0	2,779,090.0	$246,010
45	2,779,089.0	2,779,090.0	$246,010
46	2,779,089.0	2,779,090.0	$246,010
47	2,779,089.0	2,779,090.0	$246,010
48	2,779,089.0	2,779,090.0	$246,010
49	2,779,089.0	2,779,090.0	$246,010
50	2,779,089.0	2,779,090.0	$246,010

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 5
SCENARIO = 1

FLUX STANDARD = 6
THICKNESS(in meters) = .385

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	5,416,056.0	1,479,084.0	$3,483,082
2	5,404,475.0	1,572,200.0	$238,847
3	5,392,733.0	1,666,614.0	$518,745
4	5,380,822.0	1,762,389.0	$137,726
5	5,368,730.0	1,859,620.0	$543,930
6	5,356,448.0	1,958,376.0	$151,884
7	5,343,961.0	2,058,781.0	$571,147
8	5,331,256.0	2,160,940.0	$166,738
9	5,318,316.0	2,264,987.0	$600,966
10	5,305,124.0	2,371,062.0	$182,426
11	5,291,658.0	2,479,343.0	$634,008
12	5,277,893.0	2,590,023.0	$199,164
13	5,263,803.0	2,703,323.0	$671,273
14	5,249,352.0	2,819,517.0	$217,249
15	4,974,273.0	4,974,273.0	$6,667,811
16	4,974,273.0	4,974,273.0	$357,865
17	4,974,273.0	4,974,273.0	$357,865
18	4,974,273.0	4,974,273.0	$357,865
19	4,974,273.0	4,974,273.0	$357,865
20	4,974,273.0	4,974,273.0	$357,865
21	4,974,273.0	4,974,273.0	$357,865
22	4,974,273.0	4,974,273.0	$357,865
23	4,974,273.0	4,974,273.0	$357,865
24	4,974,273.0	4,974,273.0	$357,865
25	4,974,273.0	4,974,273.0	$357,865
26	4,974,273.0	4,974,273.0	$357,865
27	4,974,273.0	4,974,273.0	$357,865
28	4,974,273.0	4,974,273.0	$357,865
29	4,974,273.0	4,974,273.0	$357,865
30	4,974,273.0	4,974,273.0	$357,865
31	4,974,273.0	4,974,273.0	$357,865
32	4,974,273.0	4,974,273.0	$357,865
33	4,974,273.0	4,974,273.0	$357,865
34	4,974,273.0	4,974,273.0	$357,865
35	4,974,273.0	4,974,273.0	$357,865
36	4,974,273.0	4,974,273.0	$357,865
37	4,974,273.0	4,974,273.0	$357,865
38	4,974,273.0	4,974,273.0	$357,865
39	4,974,273.0	4,974,273.0	$357,865
40	4,974,273.0	4,974,273.0	$357,865
41	4,974,273.0	4,974,273.0	$357,865
42	4,974,273.0	4,974,273.0	$357,865
43	4,974,273.0	4,974,273.0	$357,865
44	4,974,273.0	4,974,273.0	$357,865
45	4,974,273.0	4,974,273.0	$357,865
46	4,974,273.0	4,974,273.0	$357,865
47	4,974,273.0	4,974,273.0	$357,865
48	4,974,273.0	4,974,273.0	$357,865
49	4,974,273.0	4,974,273.0	$357,865
50	4,974,273.0	4,974,273.0	$357,865

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 6 FLUX STANDARD = 6
SCENARIO = 1 THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	6,215,071.0	2,130,217.0	$5,271,046
2	4,882,716.0	4,882,717.0	$11,563,100
3	4,882,716.0	4,882,717.0	$433,433
4	4,882,716.0	4,882,717.0	$433,433
5	4,882,716.0	4,882,717.0	$433,433
6	4,882,716.0	4,882,717.0	$433,433
7	4,882,716.0	4,882,717.0	$433,433
8	4,882,716.0	4,882,717.0	$433,433
9	4,882,716.0	4,882,717.0	$433,433
10	4,882,716.0	4,882,717.0	$433,433
11	4,882,716.0	4,882,717.0	$433,433
12	4,882,716.0	4,882,717.0	$433,433
13	4,882,716.0	4,882,717.0	$433,433
14	4,882,716.0	4,882,717.0	$433,433
15	4,882,716.0	4,882,717.0	$551,851
16	4,882,716.0	4,882,717.0	$433,433
17	4,882,716.0	4,882,717.0	$433,433
18	4,882,716.0	4,882,717.0	$433,433
19	4,882,716.0	4,882,717.0	$433,433
20	4,882,716.0	4,882,717.0	$433,433
21	4,882,716.0	4,882,717.0	$433,433
22	4,882,716.0	4,882,717.0	$433,433
23	4,882,716.0	4,882,717.0	$433,433
24	4,882,716.0	4,882,717.0	$433,433
25	4,882,716.0	4,882,717.0	$433,433
26	4,882,716.0	4,882,717.0	$433,433
27	4,882,716.0	4,882,717.0	$433,433
28	4,882,716.0	4,882,717.0	$433,433
29	4,882,716.0	4,882,717.0	$433,433
30	4,882,716.0	4,882,717.0	$433,433
31	4,882,716.0	4,882,717.0	$433,433
32	4,882,716.0	4,882,717.0	$433,433
33	4,882,716.0	4,882,717.0	$433,433
34	4,882,716.0	4,882,717.0	$433,433
35	4,882,716.0	4,882,717.0	$433,433
36	4,882,716.0	4,882,717.0	$433,433
37	4,882,716.0	4,882,717.0	$433,433
38	4,882,716.0	4,882,717.0	$433,433
39	4,882,716.0	4,882,717.0	$433,433
40	4,882,716.0	4,882,717.0	$433,433
41	4,882,716.0	4,882,717.0	$433,433
42	4,882,716.0	4,882,717.0	$433,433
43	4,882,716.0	4,882,717.0	$433,433
44	4,882,716.0	4,882,717.0	$433,433
45	4,882,716.0	4,882,717.0	$433,433
46	4,882,716.0	4,882,717.0	$433,433
47	4,882,716.0	4,882,717.0	$433,433
48	4,882,716.0	4,882,717.0	$433,433
49	4,882,716.0	4,882,717.0	$433,433
50	4,882,716.0	4,882,717.0	$433,433

EFFECTS OF CONTROLS FOR STACK 7
SCENARIO = 1

FLUX STANDARD = 6
THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	4,426,291.0	4,426,293.0	$16,437,950
2	4,426,291.0	4,426,293.0	$549,788
3	4,426,291.0	4,426,293.0	$426,823
4	4,426,291.0	4,426,293.0	$426,823
5	4,426,291.0	4,426,293.0	$426,823
6	4,426,291.0	4,426,293.0	$426,823
7	4,426,291.0	4,426,293.0	$426,823
8	4,426,291.0	4,426,293.0	$426,823
9	4,426,291.0	4,426,293.0	$426,823
10	4,426,291.0	4,426,293.0	$426,823
11	4,426,291.0	4,426,293.0	$426,823
12	4,426,291.0	4,426,293.0	$426,823
13	4,426,291.0	4,426,293.0	$426,823
14	4,426,291.0	4,426,293.0	$426,823
15	4,426,291.0	4,426,293.0	$426,823
16	4,426,291.0	4,426,293.0	$426,823
17	4,426,291.0	4,426,293.0	$426,823
18	4,426,291.0	4,426,293.0	$426,823
19	4,426,291.0	4,426,293.0	$426,823
20	4,426,291.0	4,426,293.0	$426,823
21	4,426,291.0	4,426,293.0	$426,823
22	4,426,291.0	4,426,293.0	$426,823
23	4,426,291.0	4,426,293.0	$426,823
24	4,426,291.0	4,426,293.0	$426,823
25	4,426,291.0	4,426,293.0	$426,823
26	4,426,291.0	4,426,293.0	$426,823
27	4,426,291.0	4,426,293.0	$426,823
28	4,426,291.0	4,426,293.0	$426,823
29	4,426,291.0	4,426,293.0	$426,823
30	4,426,291.0	4,426,293.0	$426,823
31	4,426,291.0	4,426,293.0	$426,823
32	4,426,291.0	4,426,293.0	$426,823
33	4,426,291.0	4,426,293.0	$426,823
34	4,426,291.0	4,426,293.0	$426,823
35	4,426,291.0	4,426,293.0	$426,823
36	4,426,291.0	4,426,293.0	$426,823
37	4,426,291.0	4,426,293.0	$426,823
38	4,426,291.0	4,426,293.0	$426,823
39	4,426,291.0	4,426,293.0	$426,823
40	4,426,291.0	4,426,293.0	$426,823
41	4,426,291.0	4,426,293.0	$426,823
42	4,426,291.0	4,426,293.0	$426,823
43	4,426,291.0	4,426,293.0	$426,823
44	4,426,291.0	4,426,293.0	$426,823
45	4,426,291.0	4,426,293.0	$426,823
46	4,426,291.0	4,426,293.0	$426,823
47	4,426,291.0	4,426,293.0	$426,823
48	4,426,291.0	4,426,293.0	$426,823
49	4,426,291.0	4,426,293.0	$426,823
50	4,426,291.0	4,426,293.0	$426,823

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 8　　FLUX STANDARD = 6
SCENARIO = 1　　THICKNESS(in meters) = 1.021

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	782,914.9	465,472.9	$1,490,111
2	782,914.9	465,472.9	$16,873
3	782,914.9	465,472.9	$16,873
4	782,914.9	465,472.9	$16,873
5	782,914.9	465,472.9	$16,873
6	782,914.9	465,472.9	$16,873
7	782,914.9	465,472.9	$16,873
8	782,914.9	465,472.9	$16,873
9	782,914.9	465,472.9	$16,873
10	782,914.9	465,472.9	$16,873
11	782,914.9	465,472.9	$16,873
12	782,914.9	465,472.9	$16,873
13	782,914.9	465,472.9	$16,873
14	782,914.9	465,472.9	$16,873
15	782,914.9	465,472.9	$16,873
16	782,914.9	465,472.9	$16,873
17	782,914.9	465,472.9	$16,873
18	782,914.9	465,472.9	$16,873
19	782,914.9	465,472.9	$16,873
20	782,914.9	465,472.9	$16,873
21	782,914.9	465,472.9	$16,873
22	782,914.9	465,472.9	$16,873
23	782,914.9	465,472.9	$16,873
24	782,914.9	465,472.9	$16,873
25	782,914.9	465,472.9	$16,873
26	782,914.9	465,472.9	$16,873
27	782,914.9	465,472.9	$16,873
28	782,914.9	465,472.9	$16,873
29	782,914.9	465,472.9	$16,873
30	782,914.9	465,472.9	$16,873
31	782,914.9	465,472.9	$16,873
32	782,914.9	465,472.9	$16,873
33	782,914.9	465,472.9	$16,873
34	782,914.9	465,472.9	$16,873
35	782,914.9	465,472.9	$16,873
36	782,914.9	465,472.9	$16,873
37	782,914.9	465,472.9	$16,873
38	782,914.9	465,472.9	$16,873
39	782,914.9	465,472.9	$16,873
40	782,914.9	465,472.9	$16,873
41	782,914.9	465,472.9	$16,873
42	782,914.9	465,472.9	$16,873
43	782,914.9	465,472.9	$16,873
44	782,914.9	465,472.9	$16,873
45	782,914.9	465,472.9	$16,873
46	782,914.9	465,472.9	$16,873
47	782,914.9	465,472.9	$16,873
48	782,914.9	465,472.9	$16,873
49	782,914.9	465,472.9	$16,873
50	782,914.9	465,472.9	$16,873

EFFECTS OF CONTROLS FOR STACK 9 FLUX STANDARD = 6
SCENARIO = 1 THICKNESS(in meters) = .533

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,537,234.0	504,667.4	$1,565,006
2	1,530,636.0	557,725.8	$49,588
3	1,523,828.0	612,463.9	$356,993
4	1,516,782.0	669,117.9	$58,680
5	1,509,461.0	727,990.0	$388,441
6	1,501,815.0	789,469.8	$69,201
7	1,493,778.0	854,095.0	$429,750
8	1,458,635.0	1,458,635.0	$2,296,933
9	1,458,635.0	1,458,635.0	$101,419
10	1,458,635.0	1,458,635.0	$101,419
11	1,458,635.0	1,458,635.0	$101,419
12	1,458,635.0	1,458,635.0	$101,419
13	1,458,635.0	1,458,635.0	$101,419
14	1,458,635.0	1,458,635.0	$101,419
15	1,458,635.0	1,458,635.0	$101,419
16	1,458,635.0	1,458,635.0	$101,419
17	1,458,635.0	1,458,635.0	$101,419
18	1,458,635.0	1,458,635.0	$101,419
19	1,458,635.0	1,458,635.0	$101,419
20	1,458,635.0	1,458,635.0	$101,419
21	1,458,635.0	1,458,635.0	$101,419
22	1,458,635.0	1,458,635.0	$101,419
23	1,458,635.0	1,458,635.0	$101,419
24	1,458,635.0	1,458,635.0	$101,419
25	1,458,635.0	1,458,635.0	$101,419
26	1,458,635.0	1,458,635.0	$101,419
27	1,458,635.0	1,458,635.0	$101,419
28	1,458,635.0	1,458,635.0	$101,419
29	1,458,635.0	1,458,635.0	$101,419
30	1,458,635.0	1,458,635.0	$101,419
31	1,458,635.0	1,458,635.0	$101,419
32	1,458,635.0	1,458,635.0	$101,419
33	1,458,635.0	1,458,635.0	$101,419
34	1,458,635.0	1,458,635.0	$101,419
35	1,458,635.0	1,458,635.0	$101,419
36	1,458,635.0	1,458,635.0	$101,419
37	1,458,635.0	1,458,635.0	$101,419
38	1,458,635.0	1,458,635.0	$101,419
39	1,458,635.0	1,458,635.0	$101,419
40	1,458,635.0	1,458,635.0	$101,419
41	1,458,635.0	1,458,635.0	$101,419
42	1,458,635.0	1,458,635.0	$101,419
43	1,458,635.0	1,458,635.0	$101,419
44	1,458,635.0	1,458,635.0	$101,419
45	1,458,635.0	1,458,635.0	$101,419
46	1,458,635.0	1,458,635.0	$101,419
47	1,458,635.0	1,458,635.0	$101,419
48	1,458,635.0	1,458,635.0	$101,419
49	1,458,635.0	1,458,635.0	$101,419
50	1,458,635.0	1,458,635.0	$101,419

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 10 FLUX STANDARD = 6
SCENARIO = 1 THICKNESS(in meters) = .333

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	241,192.0	277,992.9	$785,422
2	241,192.0	277,992.9	$24,004
3	241,192.0	277,992.9	$24,004
4	241,192.0	277,992.9	$24,004
5	241,192.0	277,992.9	$24,004
6	241,192.0	277,992.9	$24,004
7	241,192.0	277,992.9	$24,004
8	241,192.0	277,992.9	$24,004
9	241,192.0	277,992.9	$24,004
10	241,192.0	277,992.9	$24,004
11	241,192.0	277,992.9	$24,004
12	241,192.0	277,992.9	$24,004
13	241,192.0	277,992.9	$24,004
14	241,192.0	277,992.9	$24,004
15	241,192.0	277,992.9	$24,004
16	241,192.0	277,992.9	$24,004
17	241,192.0	277,992.9	$24,004
18	241,192.0	277,992.9	$24,004
19	241,192.0	277,992.9	$24,004
20	241,192.0	277,992.9	$24,004
21	241,192.0	277,992.9	$24,004
22	241,192.0	277,992.9	$24,004
23	241,192.0	277,992.9	$24,004
24	241,192.0	277,992.9	$24,004
25	241,192.0	277,992.9	$24,004
26	241,192.0	277,992.9	$24,004
27	241,192.0	277,992.9	$24,004
28	241,192.0	277,992.9	$24,004
29	241,192.0	277,992.9	$24,004
30	241,192.0	277,992.9	$24,004
31	241,192.0	277,992.9	$24,004
32	241,192.0	277,992.9	$24,004
33	241,192.0	277,992.9	$24,004
34	241,192.0	277,992.9	$24,004
35	241,192.0	277,992.9	$24,004
36	241,192.0	277,992.9	$24,004
37	241,192.0	277,992.9	$24,004
38	241,192.0	277,992.9	$24,004
39	241,192.0	277,992.9	$24,004
40	241,192.0	277,992.9	$24,004
41	241,192.0	277,992.9	$24,004
42	241,192.0	277,992.9	$24,004
43	241,192.0	277,992.9	$24,004
44	241,192.0	277,992.9	$24,004
45	241,192.0	277,992.9	$24,004
46	241,192.0	277,992.9	$24,004
47	241,192.0	277,992.9	$24,004
48	241,192.0	277,992.9	$24,004
49	241,192.0	277,992.9	$24,004
50	241,192.0	277,992.9	$24,004

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 11 FLUX STANDARD = 6
SCENARIO = 1 THICKNESS(in meters) = .333

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	10,304,620.0	5,092,054.0	$10,492,430
2	10,212,840.0	5,534,859.0	$470,067
3	9,268,822.0	10,028,950.0	$12,462,450
4	9,268,822.0	10,028,950.0	$712,741
5	9,268,822.0	10,028,950.0	$712,741
6	9,268,822.0	10,028,950.0	$712,741
7	9,268,822.0	10,028,950.0	$712,741
8	9,268,822.0	10,028,950.0	$712,741
9	9,268,822.0	10,028,950.0	$712,741
10	9,268,822.0	10,028,950.0	$712,741
11	9,268,822.0	10,028,950.0	$712,741
12	9,268,822.0	10,028,950.0	$712,741
13	9,268,822.0	10,028,950.0	$712,741
14	9,268,822.0	10,028,950.0	$712,741
15	9,268,822.0	10,028,950.0	$712,741
16	9,268,822.0	10,028,950.0	$712,741
17	9,268,822.0	10,028,950.0	$712,741
18	9,268,822.0	10,028,950.0	$712,741
19	9,268,822.0	10,028,950.0	$712,741
20	9,268,822.0	10,028,950.0	$712,741
21	9,268,822.0	10,028,950.0	$712,741
22	9,268,822.0	10,028,950.0	$712,741
23	9,268,822.0	10,028,950.0	$712,741
24	9,268,822.0	10,028,950.0	$712,741
25	9,268,822.0	10,028,950.0	$712,741
26	9,268,822.0	10,028,950.0	$712,741
27	9,268,822.0	10,028,950.0	$712,741
28	9,268,822.0	10,028,950.0	$712,741
29	9,268,822.0	10,028,950.0	$712,741
30	9,268,822.0	10,028,950.0	$712,741
31	9,268,822.0	10,028,950.0	$712,741
32	9,268,822.0	10,028,950.0	$712,741
33	9,268,822.0	10,028,950.0	$712,741
34	9,268,822.0	10,028,950.0	$712,741
35	9,268,822.0	10,028,950.0	$712,741
36	9,268,822.0	10,028,950.0	$712,741
37	9,268,822.0	10,028,950.0	$712,741
38	9,268,822.0	10,028,950.0	$712,741
39	9,268,822.0	10,028,950.0	$712,741
40	9,268,822.0	10,028,950.0	$712,741
41	9,268,822.0	10,028,950.0	$712,741
42	9,268,822.0	10,028,950.0	$712,741
43	9,268,822.0	10,028,950.0	$712,741
44	9,268,822.0	10,028,950.0	$712,741
45	9,268,822.0	10,028,950.0	$712,741
46	9,268,822.0	10,028,950.0	$712,741
47	9,268,822.0	10,028,950.0	$712,741
48	9,268,822.0	10,028,950.0	$712,741
49	9,268,822.0	10,028,950.0	$712,741
50	9,268,822.0	10,028,950.0	$712,741

EFFECTS OF CONTROLS FOR STACK 12 FLUX STANDARD = 6
SCENARIO = 1 THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	883,905.8	611,849.8	$1,537,133
2	883,905.8	611,849.8	$39,430
3	883,905.8	611,849.8	$69,991
4	883,905.8	611,849.8	$39,430
5	883,905.8	611,849.8	$39,430
6	883,905.8	611,849.8	$39,430
7	883,905.8	611,849.8	$39,430
8	883,905.8	611,849.8	$39,430
9	883,905.8	611,849.8	$39,430
10	883,905.8	611,849.8	$39,430
11	883,905.8	611,849.8	$39,430
12	883,905.8	611,849.8	$39,430
13	883,905.8	611,849.8	$39,430
14	883,905.8	611,849.8	$39,430
15	883,905.8	611,849.8	$39,430
16	883,905.8	611,849.8	$39,430
17	883,905.8	611,849.8	$39,430
18	883,905.8	611,849.8	$39,430
19	883,905.8	611,849.8	$39,430
20	883,905.8	611,849.8	$39,430
21	883,905.8	611,849.8	$39,430
22	883,905.8	611,849.8	$39,430
23	883,905.8	611,849.8	$39,430
24	883,905.8	611,849.8	$39,430
25	883,905.8	611,849.8	$39,430
26	883,905.8	611,849.8	$39,430
27	883,905.8	611,849.8	$39,430
28	883,905.8	611,849.8	$39,430
29	883,905.8	611,849.8	$39,430
30	883,905.8	611,849.8	$39,430
31	883,905.8	611,849.8	$39,430
32	883,905.8	611,849.8	$39,430
33	883,905.8	611,849.8	$39,430
34	883,905.8	611,849.8	$39,430
35	883,905.8	611,849.8	$39,430
36	883,905.8	611,849.8	$39,430
37	883,905.8	611,849.8	$39,430
38	883,905.8	611,849.8	$39,430
39	883,905.8	611,849.8	$39,430
40	883,905.8	611,849.8	$39,430
41	883,905.8	611,849.8	$39,430
42	883,905.8	611,849.8	$39,430
43	883,905.8	611,849.8	$39,430
44	883,905.8	611,849.8	$39,430
45	883,905.8	611,849.8	$39,430
46	883,905.8	611,849.8	$39,430
47	883,905.8	611,849.8	$39,430
48	883,905.8	611,849.8	$39,430
49	883,905.8	611,849.8	$39,430
50	883,905.8	611,849.8	$39,430

EFFECTS OF CONTROLS FOR STACK 13
SCENARIO = 1

FLUX STANDARD = 6
THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,341,587.0	791,326.3	$1,978,028
2	1,341,587.0	791,326.3	$50,997
3	1,341,587.0	791,326.3	$50,997
4	1,341,587.0	791,326.3	$50,997
5	1,341,587.0	791,326.3	$50,997
6	1,341,587.0	791,326.3	$50,997
7	1,341,587.0	791,326.3	$50,997
8	1,341,587.0	791,326.3	$50,997
9	1,341,587.0	791,326.3	$50,997
10	1,341,587.0	791,326.3	$50,997
11	1,341,587.0	791,326.3	$50,997
12	1,341,587.0	791,326.3	$50,997
13	1,341,587.0	791,326.3	$50,997
14	1,341,587.0	791,326.3	$50,997
15	1,341,587.0	791,326.3	$50,997
16	1,341,587.0	791,326.3	$50,997
17	1,341,587.0	791,326.3	$50,997
18	1,341,587.0	791,326.3	$50,997
19	1,341,587.0	791,326.3	$50,997
20	1,341,587.0	791,326.3	$50,997
21	1,341,587.0	791,326.3	$50,997
22	1,341,587.0	791,326.3	$50,997
23	1,341,587.0	791,326.3	$50,997
24	1,341,587.0	791,326.3	$50,997
25	1,341,587.0	791,326.3	$50,997
26	1,341,587.0	791,326.3	$50,997
27	1,341,587.0	791,326.3	$50,997
28	1,341,587.0	791,326.3	$50,997
29	1,341,587.0	791,326.3	$50,997
30	1,341,587.0	791,326.3	$50,997
31	1,341,587.0	791,326.3	$50,997
32	1,341,587.0	791,326.3	$50,997
33	1,341,587.0	791,326.3	$50,997
34	1,341,587.0	791,326.3	$50,997
35	1,341,587.0	791,326.3	$50,997
36	1,341,587.0	791,326.3	$50,997
37	1,341,587.0	791,326.3	$50,997
38	1,341,587.0	791,326.3	$50,997
39	1,341,587.0	791,326.3	$50,997
40	1,341,587.0	791,326.3	$50,997
41	1,341,587.0	791,326.3	$50,997
42	1,341,587.0	791,326.3	$50,997
43	1,341,587.0	791,326.3	$50,997
44	1,341,587.0	791,326.3	$50,997
45	1,341,587.0	791,326.3	$50,997
46	1,341,587.0	791,326.3	$50,997
47	1,341,587.0	791,326.3	$50,997
48	1,341,587.0	791,326.3	$50,997
49	1,341,587.0	791,326.3	$50,997
50	1,341,587.0	791,326.3	$50,997

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 14 FLUX STANDARD = 6
SCENARIO = 1 THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	2,279,844.0	1,287,766.0	$3,213,185
2	2,213,060.0	2,213,060.0	$2,857,951
3	2,213,060.0	2,213,060.0	$154,915
4	2,213,060.0	2,213,060.0	$154,915
5	2,213,060.0	2,213,060.0	$154,915
6	2,213,060.0	2,213,060.0	$154,915
7	2,213,060.0	2,213,060.0	$154,915
8	2,213,060.0	2,213,060.0	$154,915
9	2,213,060.0	2,213,060.0	$154,915
10	2,213,060.0	2,213,060.0	$154,915
11	2,213,060.0	2,213,060.0	$154,915
12	2,213,060.0	2,213,060.0	$154,915
13	2,213,060.0	2,213,060.0	$154,915
14	2,213,060.0	2,213,060.0	$154,915
15	2,213,060.0	2,213,060.0	$154,915
16	2,213,060.0	2,213,060.0	$154,915
17	2,213,060.0	2,213,060.0	$154,915
18	2,213,060.0	2,213,060.0	$154,915
19	2,213,060.0	2,213,060.0	$154,915
20	2,213,060.0	2,213,060.0	$154,915
21	2,213,060.0	2,213,060.0	$154,915
22	2,213,060.0	2,213,060.0	$154,915
23	2,213,060.0	2,213,060.0	$154,915
24	2,213,060.0	2,213,060.0	$154,915
25	2,213,060.0	2,213,060.0	$154,915
26	2,213,060.0	2,213,060.0	$154,915
27	2,213,060.0	2,213,060.0	$154,915
28	2,213,060.0	2,213,060.0	$154,915
29	2,213,060.0	2,213,060.0	$154,915
30	2,213,060.0	2,213,060.0	$154,915
31	2,213,060.0	2,213,060.0	$154,915
32	2,213,060.0	2,213,060.0	$154,915
33	2,213,060.0	2,213,060.0	$154,915
34	2,213,060.0	2,213,060.0	$154,915
35	2,213,060.0	2,213,060.0	$154,915
36	2,213,060.0	2,213,060.0	$154,915
37	2,213,060.0	2,213,060.0	$154,915
38	2,213,060.0	2,213,060.0	$154,915
39	2,213,060.0	2,213,060.0	$154,915
40	2,213,060.0	2,213,060.0	$154,915
41	2,213,060.0	2,213,060.0	$154,915
42	2,213,060.0	2,213,060.0	$154,915
43	2,213,060.0	2,213,060.0	$154,915
44	2,213,060.0	2,213,060.0	$154,915
45	2,213,060.0	2,213,060.0	$154,915
46	2,213,060.0	2,213,060.0	$154,915
47	2,213,060.0	2,213,060.0	$154,915
48	2,213,060.0	2,213,060.0	$154,915
49	2,213,060.0	2,213,060.0	$154,915
50	2,213,060.0	2,213,060.0	$154,915

EFFECTS OF CONTROLS FOR STACK 1
SCENARIO = 2

FLUX STANDARD = 2
THICKNESS(in meters) = .995

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,932,166.0	0.0	$0
2	409,857.9	2,049,289.0	$6,462,955
3	409,857.9	2,049,289.0	$76,405
4	409,857.9	2,049,289.0	$76,405
5	409,857.9	2,049,289.0	$76,405
6	409,857.9	2,049,289.0	$76,405
7	409,857.9	2,049,289.0	$76,405
8	409,857.9	2,049,289.0	$76,405
9	409,857.9	2,049,289.0	$76,405
10	409,857.9	2,049,289.0	$76,405
11	409,857.9	2,049,289.0	$76,405
12	409,857.9	2,049,289.0	$76,405
13	409,857.9	2,049,289.0	$76,405
14	409,857.9	2,049,289.0	$76,405
15	409,857.9	2,049,289.0	$76,405
16	409,857.9	2,049,289.0	$76,405
17	409,857.9	2,049,289.0	$76,405
18	409,857.9	2,049,289.0	$76,405
19	409,857.9	2,049,289.0	$76,405
20	409,857.9	2,049,289.0	$76,405
21	409,857.9	2,049,289.0	$76,405
22	409,857.9	2,049,289.0	$76,405
23	409,857.9	2,049,289.0	$76,405
24	409,857.9	2,049,289.0	$76,405
25	409,857.9	2,049,289.0	$76,405
26	409,857.9	2,049,289.0	$76,405
27	409,857.9	2,049,289.0	$76,405
28	409,857.9	2,049,289.0	$76,405
29	409,857.9	2,049,289.0	$76,405
30	409,857.9	2,049,289.0	$76,405
31	409,857.9	2,049,289.0	$76,405
32	409,857.9	2,049,289.0	$76,405
33	409,857.9	2,049,289.0	$76,405
34	409,857.9	2,049,289.0	$76,405
35	409,857.9	2,049,289.0	$76,405
36	409,857.9	2,049,289.0	$76,405
37	409,857.9	2,049,289.0	$76,405
38	409,857.9	2,049,289.0	$76,405
39	409,857.9	2,049,289.0	$76,405
40	409,857.9	2,049,289.0	$76,405
41	409,857.9	2,049,289.0	$76,405
42	409,857.9	2,049,289.0	$76,405
43	409,857.9	2,049,289.0	$76,405
44	409,857.9	2,049,289.0	$76,405
45	409,857.9	2,049,289.0	$76,405
46	409,857.9	2,049,289.0	$76,405
47	409,857.9	2,049,289.0	$76,405
48	409,857.9	2,049,289.0	$76,405
49	409,857.9	2,049,289.0	$76,405
50	409,857.9	2,049,289.0	$76,405

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 2
SCENARIO = 2

FLUX STANDARD = 2
THICKNESS(in meters) = .995

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,596,768.0	0.0	$0
2	1,638,136.0	0.0	$0
3	1,680,890.0	0.0	$0
4	1,725,237.0	0.0	$0
5	1,771,445.0	0.0	$0
6	1,819,875.0	0.0	$0
7	1,871,023.0	0.0	$0
8	386,833.5	1,934,167.0	$6,911,243
9	386,833.5	1,934,167.0	$81,277
10	386,833.5	1,934,167.0	$81,277
11	386,833.5	1,934,167.0	$81,277
12	386,833.5	1,934,167.0	$81,277
13	386,833.5	1,934,167.0	$81,277
14	386,833.5	1,934,167.0	$81,277
15	386,833.5	1,934,167.0	$81,277
16	386,833.5	1,934,167.0	$81,277
17	386,833.5	1,934,167.0	$81,277
18	386,833.5	1,934,167.0	$81,277
19	386,833.5	1,934,167.0	$81,277
20	386,833.5	1,934,167.0	$81,277
21	386,833.5	1,934,167.0	$81,277
22	386,833.5	1,934,167.0	$81,277
23	386,833.5	1,934,167.0	$81,277
24	386,833.5	1,934,167.0	$81,277
25	386,833.5	1,934,167.0	$81,277
26	386,833.5	1,934,167.0	$81,277
27	386,833.5	1,934,167.0	$81,277
28	386,833.5	1,934,167.0	$81,277
29	386,833.5	1,934,167.0	$81,277
30	386,833.5	1,934,167.0	$81,277
31	386,833.5	1,934,167.0	$81,277
32	386,833.5	1,934,167.0	$81,277
33	386,833.5	1,934,167.0	$81,277
34	386,833.5	1,934,167.0	$81,277
35	386,833.5	1,934,167.0	$81,277
36	386,833.5	1,934,167.0	$81,277
37	386,833.5	1,934,167.0	$81,277
38	386,833.5	1,934,167.0	$81,277
39	386,833.5	1,934,167.0	$81,277
40	386,833.5	1,934,167.0	$81,277
41	386,833.5	1,934,167.0	$81,277
42	386,833.5	1,934,167.0	$81,277
43	386,833.5	1,934,167.0	$81,277
44	386,833.5	1,934,167.0	$81,277
45	386,833.5	1,934,167.0	$81,277
46	386,833.5	1,934,167.0	$81,277
47	386,833.5	1,934,167.0	$81,277
48	386,833.5	1,934,167.0	$81,277
49	386,833.5	1,934,167.0	$81,277
50	386,833.5	1,934,167.0	$81,277

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 3 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = .333

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	354,356.6	291,323.3	$4,635,814
2	354,356.6	291,323.3	$141,610
3	354,356.6	291,323.3	$141,610
4	354,356.6	291,323.3	$141,610
5	354,356.6	291,323.3	$141,610
6	354,356.6	291,323.3	$141,610
7	354,356.6	291,323.3	$141,610
8	354,356.6	291,323.3	$141,610
9	354,356.6	291,323.3	$141,610
10	354,356.6	291,323.3	$141,610
11	354,356.6	291,323.3	$141,610
12	354,356.6	291,323.3	$141,610
13	354,356.6	291,323.3	$141,610
14	354,356.6	291,323.3	$141,610
15	354,356.6	291,323.3	$141,610
16	354,356.6	291,323.3	$141,610
17	354,356.6	291,323.3	$141,610
18	354,356.6	291,323.3	$141,610
19	354,356.6	291,323.3	$141,610
20	354,356.6	291,323.3	$141,610
21	354,356.6	291,323.3	$141,610
22	354,356.6	291,323.3	$141,610
23	354,356.6	291,323.3	$141,610
24	354,356.6	291,323.3	$141,610
25	354,356.6	291,323.3	$141,610
26	354,356.6	291,323.3	$141,610
27	354,356.6	291,323.3	$141,610
28	354,356.6	291,323.3	$141,610
29	354,356.6	291,323.3	$141,610
30	354,356.6	291,323.3	$141,610
31	354,356.6	291,323.3	$141,610
32	354,356.6	291,323.3	$141,610
33	354,356.6	291,323.3	$141,610
34	354,356.6	291,323.3	$141,610
35	354,356.6	291,323.3	$141,610
36	354,356.6	291,323.3	$141,610
37	354,356.6	291,323.3	$141,610
38	354,356.6	291,323.3	$141,610
39	354,356.6	291,323.3	$141,610
40	354,356.6	291,323.3	$141,610
41	354,356.6	291,323.3	$141,610
42	354,356.6	291,323.3	$141,610
43	354,356.6	291,323.3	$141,610
44	354,356.6	291,323.3	$141,610
45	354,356.6	291,323.3	$141,610
46	354,356.6	291,323.3	$141,610
47	354,356.6	291,323.3	$141,610
48	354,356.6	291,323.3	$141,610
49	354,356.6	291,323.3	$141,610
50	354,356.6	291,323.3	$141,610

EFFECTS OF CONTROLS FOR STACK 4 FLUX STANDARD = 2
SCENARIO = 2 THICKNESS(in meters) = 1.054

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	4,746,327.0	0.0	$0
2	926,363.2	4,631,816.0	$21,934,520
3	926,363.2	4,631,816.0	$246,010
4	926,363.2	4,631,816.0	$246,010
5	926,363.2	4,631,816.0	$246,010
6	926,363.2	4,631,816.0	$246,010
7	926,363.2	4,631,816.0	$246,010
8	926,363.2	4,631,816.0	$246,010
9	926,363.2	4,631,816.0	$246,010
10	926,363.2	4,631,816.0	$246,010
11	926,363.2	4,631,816.0	$246,010
12	926,363.2	4,631,816.0	$246,010
13	926,363.2	4,631,816.0	$246,010
14	926,363.2	4,631,816.0	$246,010
15	926,363.2	4,631,816.0	$246,010
16	926,363.2	4,631,816.0	$246,010
17	926,363.2	4,631,816.0	$246,010
18	926,363.2	4,631,816.0	$246,010
19	926,363.2	4,631,816.0	$246,010
20	926,363.2	4,631,816.0	$246,010
21	926,363.2	4,631,816.0	$246,010
22	926,363.2	4,631,816.0	$246,010
23	926,363.2	4,631,816.0	$246,010
24	926,363.2	4,631,816.0	$246,010
25	926,363.2	4,631,816.0	$246,010
26	926,363.2	4,631,816.0	$246,010
27	926,363.2	4,631,816.0	$246,010
28	926,363.2	4,631,816.0	$246,010
29	926,363.2	4,631,816.0	$246,010
30	926,363.2	4,631,816.0	$246,010
31	926,363.2	4,631,816.0	$246,010
32	926,363.2	4,631,816.0	$246,010
33	926,363.2	4,631,816.0	$246,010
34	926,363.2	4,631,816.0	$246,010
35	926,363.2	4,631,816.0	$246,010
36	926,363.2	4,631,816.0	$246,010
37	926,363.2	4,631,816.0	$246,010
38	926,363.2	4,631,816.0	$246,010
39	926,363.2	4,631,816.0	$246,010
40	926,363.2	4,631,816.0	$246,010
41	926,363.2	4,631,816.0	$246,010
42	926,363.2	4,631,816.0	$246,010
43	926,363.2	4,631,816.0	$246,010
44	926,363.2	4,631,816.0	$246,010
45	926,363.2	4,631,816.0	$246,010
46	926,363.2	4,631,816.0	$246,010
47	926,363.2	4,631,816.0	$246,010
48	926,363.2	4,631,816.0	$246,010
49	926,363.2	4,631,816.0	$246,010
50	926,363.2	4,631,816.0	$246,010

EFFECTS OF CONTROLS FOR STACK 1
SCENARIO = 2

FLUX STANDARD = 6
THICKNESS(in meters) = .385

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,932,166.0	0.0	$0
2	1,229,574.0	1,229,574.0	$2,835,224
3	1,229,574.0	1,229,574.0	$76,405
4	1,229,574.0	1,229,574.0	$76,405
5	1,229,574.0	1,229,574.0	$76,405
6	1,229,574.0	1,229,574.0	$76,405
7	1,229,574.0	1,229,574.0	$76,405
8	1,229,574.0	1,229,574.0	$76,405
9	1,229,574.0	1,229,574.0	$76,405
10	1,229,574.0	1,229,574.0	$76,405
11	1,229,574.0	1,229,574.0	$76,405
12	1,229,574.0	1,229,574.0	$76,405
13	1,229,574.0	1,229,574.0	$76,405
14	1,229,574.0	1,229,574.0	$76,405
15	1,229,574.0	1,229,574.0	$76,405
16	1,229,574.0	1,229,574.0	$76,405
17	1,229,574.0	1,229,574.0	$76,405
18	1,229,574.0	1,229,574.0	$76,405
19	1,229,574.0	1,229,574.0	$76,405
20	1,229,574.0	1,229,574.0	$76,405
21	1,229,574.0	1,229,574.0	$76,405
22	1,229,574.0	1,229,574.0	$76,405
23	1,229,574.0	1,229,574.0	$76,405
24	1,229,574.0	1,229,574.0	$76,405
25	1,229,574.0	1,229,574.0	$76,405
26	1,229,574.0	1,229,574.0	$76,405
27	1,229,574.0	1,229,574.0	$76,405
28	1,229,574.0	1,229,574.0	$76,405
29	1,229,574.0	1,229,574.0	$76,405
30	1,229,574.0	1,229,574.0	$76,405
31	1,229,574.0	1,229,574.0	$76,405
32	1,229,574.0	1,229,574.0	$76,405
33	1,229,574.0	1,229,574.0	$76,405
34	1,229,574.0	1,229,574.0	$76,405
35	1,229,574.0	1,229,574.0	$76,405
36	1,229,574.0	1,229,574.0	$76,405
37	1,229,574.0	1,229,574.0	$76,405
38	1,229,574.0	1,229,574.0	$76,405
39	1,229,574.0	1,229,574.0	$76,405
40	1,229,574.0	1,229,574.0	$76,405
41	1,229,574.0	1,229,574.0	$76,405
42	1,229,574.0	1,229,574.0	$76,405
43	1,229,574.0	1,229,574.0	$76,405
44	1,229,574.0	1,229,574.0	$76,405
45	1,229,574.0	1,229,574.0	$76,405
46	1,229,574.0	1,229,574.0	$76,405
47	1,229,574.0	1,229,574.0	$76,405
48	1,229,574.0	1,229,574.0	$76,405
49	1,229,574.0	1,229,574.0	$76,405
50	1,229,574.0	1,229,574.0	$76,405

EFFECTS OF CONTROLS FOR STACK 2 FLUX STANDARD = 6
SCENARIO = 2 THICKNESS(in meters) = .385

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,596,768.0	0.0	$0
2	1,638,136.0	0.0	$0
3	1,680,890.0	0.0	$0
4	1,725,237.0	0.0	$0
5	1,771,445.0	0.0	$0
6	1,819,875.0	0.0	$0
7	1,871,023.0	0.0	$0
8	1,160,500.0	1,160,501.0	$3,052,193
9	1,160,500.0	1,160,501.0	$81,277
10	1,160,500.0	1,160,501.0	$81,277
11	1,160,500.0	1,160,501.0	$81,277
12	1,160,500.0	1,160,501.0	$81,277
13	1,160,500.0	1,160,501.0	$81,277
14	1,160,500.0	1,160,501.0	$81,277
15	1,160,500.0	1,160,501.0	$81,277
16	1,160,500.0	1,160,501.0	$81,277
17	1,160,500.0	1,160,501.0	$81,277
18	1,160,500.0	1,160,501.0	$81,277
19	1,160,500.0	1,160,501.0	$81,277
20	1,160,500.0	1,160,501.0	$81,277
21	1,160,500.0	1,160,501.0	$81,277
22	1,160,500.0	1,160,501.0	$81,277
23	1,160,500.0	1,160,501.0	$81,277
24	1,160,500.0	1,160,501.0	$81,277
25	1,160,500.0	1,160,501.0	$81,277
26	1,160,500.0	1,160,501.0	$81,277
27	1,160,500.0	1,160,501.0	$81,277
28	1,160,500.0	1,160,501.0	$81,277
29	1,160,500.0	1,160,501.0	$81,277
30	1,160,500.0	1,160,501.0	$81,277
31	1,160,500.0	1,160,501.0	$81,277
32	1,160,500.0	1,160,501.0	$81,277
33	1,160,500.0	1,160,501.0	$81,277
34	1,160,500.0	1,160,501.0	$81,277
35	1,160,500.0	1,160,501.0	$81,277
36	1,160,500.0	1,160,501.0	$81,277
37	1,160,500.0	1,160,501.0	$81,277
38	1,160,500.0	1,160,501.0	$81,277
39	1,160,500.0	1,160,501.0	$81,277
40	1,160,500.0	1,160,501.0	$81,277
41	1,160,500.0	1,160,501.0	$81,277
42	1,160,500.0	1,160,501.0	$81,277
43	1,160,500.0	1,160,501.0	$81,277
44	1,160,500.0	1,160,501.0	$81,277
45	1,160,500.0	1,160,501.0	$81,277
46	1,160,500.0	1,160,501.0	$81,277
47	1,160,500.0	1,160,501.0	$81,277
48	1,160,500.0	1,160,501.0	$81,277
49	1,160,500.0	1,160,501.0	$81,277
50	1,160,500.0	1,160,501.0	$81,277

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 3 FLUX STANDARD = 6
SCENARIO = 2 THICKNESS(in meters) = .333

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	354,356.6	291,323.3	$4,635,814
2	354,356.6	291,323.3	$141,610
3	354,356.6	291,323.3	$141,610
4	354,356.6	291,323.3	$141,610
5	354,356.6	291,323.3	$141,610
6	354,356.6	291,323.3	$141,610
7	354,356.6	291,323.3	$141,610
8	354,356.6	291,323.3	$141,610
9	354,356.6	291,323.3	$141,610
10	354,356.6	291,323.3	$141,610
11	354,356.6	291,323.3	$141,610
12	354,356.6	291,323.3	$141,610
13	354,356.6	291,323.3	$141,610
14	354,356.6	291,323.3	$141,610
15	354,356.6	291,323.3	$141,610
16	354,356.6	291,323.3	$141,610
17	354,356.6	291,323.3	$141,610
18	354,356.6	291,323.3	$141,610
19	354,356.6	291,323.3	$141,610
20	354,356.6	291,323.3	$141,610
21	354,356.6	291,323.3	$141,610
22	354,356.6	291,323.3	$141,610
23	354,356.6	291,323.3	$141,610
24	354,356.6	291,323.3	$141,610
25	354,356.6	291,323.3	$141,610
26	354,356.6	291,323.3	$141,610
27	354,356.6	291,323.3	$141,610
28	354,356.6	291,323.3	$141,610
29	354,356.6	291,323.3	$141,610
30	354,356.6	291,323.3	$141,610
31	354,356.6	291,323.3	$141,610
32	354,356.6	291,323.3	$141,610
33	354,356.6	291,323.3	$141,610
34	354,356.6	291,323.3	$141,610
35	354,356.6	291,323.3	$141,610
36	354,356.6	291,323.3	$141,610
37	354,356.6	291,323.3	$141,610
38	354,356.6	291,323.3	$141,610
39	354,356.6	291,323.3	$141,610
40	354,356.6	291,323.3	$141,610
41	354,356.6	291,323.3	$141,610
42	354,356.6	291,323.3	$141,610
43	354,356.6	291,323.3	$141,610
44	354,356.6	291,323.3	$141,610
45	354,356.6	291,323.3	$141,610
46	354,356.6	291,323.3	$141,610
47	354,356.6	291,323.3	$141,610
48	354,356.6	291,323.3	$141,610
49	354,356.6	291,323.3	$141,610
50	354,356.6	291,323.3	$141,610

EFFECTS OF CONTROLS FOR STACK 4
SCENARIO = 2

FLUX STANDARD = 6
THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	4,746,327.0	0.0	$0
2	2,779,089.0	2,779,090.0	$9,566,817
3	2,779,089.0	2,779,090.0	$246,010
4	2,779,089.0	2,779,090.0	$246,010
5	2,779,089.0	2,779,090.0	$246,010
6	2,779,089.0	2,779,090.0	$246,010
7	2,779,089.0	2,779,090.0	$246,010
8	2,779,089.0	2,779,090.0	$246,010
9	2,779,089.0	2,779,090.0	$246,010
10	2,779,089.0	2,779,090.0	$246,010
11	2,779,089.0	2,779,090.0	$246,010
12	2,779,089.0	2,779,090.0	$246,010
13	2,779,089.0	2,779,090.0	$246,010
14	2,779,089.0	2,779,090.0	$246,010
15	2,779,089.0	2,779,090.0	$246,010
16	2,779,089.0	2,779,090.0	$246,010
17	2,779,089.0	2,779,090.0	$246,010
18	2,779,089.0	2,779,090.0	$246,010
19	2,779,089.0	2,779,090.0	$246,010
20	2,779,089.0	2,779,090.0	$246,010
21	2,779,089.0	2,779,090.0	$246,010
22	2,779,089.0	2,779,090.0	$246,010
23	2,779,089.0	2,779,090.0	$246,010
24	2,779,089.0	2,779,090.0	$246,010
25	2,779,089.0	2,779,090.0	$246,010
26	2,779,089.0	2,779,090.0	$246,010
27	2,779,089.0	2,779,090.0	$246,010
28	2,779,089.0	2,779,090.0	$246,010
29	2,779,089.0	2,779,090.0	$246,010
30	2,779,089.0	2,779,090.0	$246,010
31	2,779,089.0	2,779,090.0	$246,010
32	2,779,089.0	2,779,090.0	$246,010
33	2,779,089.0	2,779,090.0	$246,010
34	2,779,089.0	2,779,090.0	$246,010
35	2,779,089.0	2,779,090.0	$246,010
36	2,779,089.0	2,779,090.0	$246,010
37	2,779,089.0	2,779,090.0	$246,010
38	2,779,089.0	2,779,090.0	$246,010
39	2,779,089.0	2,779,090.0	$246,010
40	2,779,089.0	2,779,090.0	$246,010
41	2,779,089.0	2,779,090.0	$246,010
42	2,779,089.0	2,779,090.0	$246,010
43	2,779,089.0	2,779,090.0	$246,010
44	2,779,089.0	2,779,090.0	$246,010
45	2,779,089.0	2,779,090.0	$246,010
46	2,779,089.0	2,779,090.0	$246,010
47	2,779,089.0	2,779,090.0	$246,010
48	2,779,089.0	2,779,090.0	$246,010
49	2,779,089.0	2,779,090.0	$246,010
50	2,779,089.0	2,779,090.0	$246,010

EFFECTS OF CONTROLS FOR STACK 5 FLUX STANDARD = 6
SCENARIO = 2 THICKNESS(in meters) = .385

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	6,895,139.0	0.0	$0
2	6,976,675.0	0.0	$0
3	7,059,347.0	0.0	$0
4	7,143,211.0	0.0	$0
5	7,228,350.0	0.0	$0
6	7,314,824.0	0.0	$0
7	7,402,742.0	0.0	$0
8	7,492,196.0	0.0	$0
9	7,583,303.0	0.0	$0
10	7,676,186.0	0.0	$0
11	7,771,001.0	0.0	$0
12	7,867,916.0	0.0	$0
13	7,967,126.0	0.0	$0
14	8,068,868.0	0.0	$0
15	4,974,273.0	4,974,273.0	$13,308,340
16	4,974,273.0	4,974,273.0	$357,865
17	4,974,273.0	4,974,273.0	$357,865
18	4,974,273.0	4,974,273.0	$357,865
19	4,974,273.0	4,974,273.0	$357,865
20	4,974,273.0	4,974,273.0	$357,865
21	4,974,273.0	4,974,273.0	$357,865
22	4,974,273.0	4,974,273.0	$357,865
23	4,974,273.0	4,974,273.0	$357,865
24	4,974,273.0	4,974,273.0	$357,865
25	4,974,273.0	4,974,273.0	$357,865
26	4,974,273.0	4,974,273.0	$357,865
27	4,974,273.0	4,974,273.0	$357,865
28	4,974,273.0	4,974,273.0	$357,865
29	4,974,273.0	4,974,273.0	$357,865
30	4,974,273.0	4,974,273.0	$357,865
31	4,974,273.0	4,974,273.0	$357,865
32	4,974,273.0	4,974,273.0	$357,865
33	4,974,273.0	4,974,273.0	$357,865
34	4,974,273.0	4,974,273.0	$357,865
35	4,974,273.0	4,974,273.0	$357,865
36	4,974,273.0	4,974,273.0	$357,865
37	4,974,273.0	4,974,273.0	$357,865
38	4,974,273.0	4,974,273.0	$357,865
39	4,974,273.0	4,974,273.0	$357,865
40	4,974,273.0	4,974,273.0	$357,865
41	4,974,273.0	4,974,273.0	$357,865
42	4,974,273.0	4,974,273.0	$357,865
43	4,974,273.0	4,974,273.0	$357,865
44	4,974,273.0	4,974,273.0	$357,865
45	4,974,273.0	4,974,273.0	$357,865
46	4,974,273.0	4,974,273.0	$357,865
47	4,974,273.0	4,974,273.0	$357,865
48	4,974,273.0	4,974,273.0	$357,865
49	4,974,273.0	4,974,273.0	$357,865
50	4,974,273.0	4,974,273.0	$357,865

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 6 FLUX STANDARD = 6
SCENARIO = 2 THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	8,345,288.0	0.0	$0
2	4,882,716.0	4,882,717.0	$16,696,870
3	4,882,716.0	4,882,717.0	$433,433
4	4,882,716.0	4,882,717.0	$433,433
5	4,882,716.0	4,882,717.0	$433,433
6	4,882,716.0	4,882,717.0	$433,433
7	4,882,716.0	4,882,717.0	$433,433
8	4,882,716.0	4,882,717.0	$433,433
9	4,882,716.0	4,882,717.0	$433,433
10	4,882,716.0	4,882,717.0	$433,433
11	4,882,716.0	4,882,717.0	$433,433
12	4,882,716.0	4,882,717.0	$433,433
13	4,882,716.0	4,882,717.0	$433,433
14	4,882,716.0	4,882,717.0	$433,433
15	4,882,716.0	4,882,717.0	$433,433
16	4,882,716.0	4,882,717.0	$433,433
17	4,882,716.0	4,882,717.0	$433,433
18	4,882,716.0	4,882,717.0	$433,433
19	4,882,716.0	4,882,717.0	$433,433
20	4,882,716.0	4,882,717.0	$433,433
21	4,882,716.0	4,882,717.0	$433,433
22	4,882,716.0	4,882,717.0	$433,433
23	4,882,716.0	4,882,717.0	$433,433
24	4,882,716.0	4,882,717.0	$433,433
25	4,882,716.0	4,882,717.0	$433,433
26	4,882,716.0	4,882,717.0	$433,433
27	4,882,716.0	4,882,717.0	$433,433
28	4,882,716.0	4,882,717.0	$433,433
29	4,882,716.0	4,882,717.0	$433,433
30	4,882,716.0	4,882,717.0	$433,433
31	4,882,716.0	4,882,717.0	$433,433
32	4,882,716.0	4,882,717.0	$433,433
33	4,882,716.0	4,882,717.0	$433,433
34	4,882,716.0	4,882,717.0	$433,433
35	4,882,716.0	4,882,717.0	$433,433
36	4,882,716.0	4,882,717.0	$433,433
37	4,882,716.0	4,882,717.0	$433,433
38	4,882,716.0	4,882,717.0	$433,433
39	4,882,716.0	4,882,717.0	$433,433
40	4,882,716.0	4,882,717.0	$433,433
41	4,882,716.0	4,882,717.0	$433,433
42	4,882,716.0	4,882,717.0	$433,433
43	4,882,716.0	4,882,717.0	$433,433
44	4,882,716.0	4,882,717.0	$433,433
45	4,882,716.0	4,882,717.0	$433,433
46	4,882,716.0	4,882,717.0	$433,433
47	4,882,716.0	4,882,717.0	$433,433
48	4,882,716.0	4,882,717.0	$433,433
49	4,882,716.0	4,882,717.0	$433,433
50	4,882,716.0	4,882,717.0	$433,433

EFFECTS OF CONTROLS FOR STACK 7 FLUX STANDARD = 6
SCENARIO = 2 THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	4,426,291.0	4,426,293.0	$16,437,950
2	4,426,291.0	4,426,293.0	$426,823
3	4,426,291.0	4,426,293.0	$426,823
4	4,426,291.0	4,426,293.0	$426,823
5	4,426,291.0	4,426,293.0	$426,823
6	4,426,291.0	4,426,293.0	$426,823
7	4,426,291.0	4,426,293.0	$426,823
8	4,426,291.0	4,426,293.0	$426,823
9	4,426,291.0	4,426,293.0	$426,823
10	4,426,291.0	4,426,293.0	$426,823
11	4,426,291.0	4,426,293.0	$426,823
12	4,426,291.0	4,426,293.0	$426,823
13	4,426,291.0	4,426,293.0	$426,823
14	4,426,291.0	4,426,293.0	$426,823
15	4,426,291.0	4,426,293.0	$426,823
16	4,426,291.0	4,426,293.0	$426,823
17	4,426,291.0	4,426,293.0	$426,823
18	4,426,291.0	4,426,293.0	$426,823
19	4,426,291.0	4,426,293.0	$426,823
20	4,426,291.0	4,426,293.0	$426,823
21	4,426,291.0	4,426,293.0	$426,823
22	4,426,291.0	4,426,293.0	$426,823
23	4,426,291.0	4,426,293.0	$426,823
24	4,426,291.0	4,426,293.0	$426,823
25	4,426,291.0	4,426,293.0	$426,823
26	4,426,291.0	4,426,293.0	$426,823
27	4,426,291.0	4,426,293.0	$426,823
28	4,426,291.0	4,426,293.0	$426,823
29	4,426,291.0	4,426,293.0	$426,823
30	4,426,291.0	4,426,293.0	$426,823
31	4,426,291.0	4,426,293.0	$426,823
32	4,426,291.0	4,426,293.0	$426,823
33	4,426,291.0	4,426,293.0	$426,823
34	4,426,291.0	4,426,293.0	$426,823
35	4,426,291.0	4,426,293.0	$426,823
36	4,426,291.0	4,426,293.0	$426,823
37	4,426,291.0	4,426,293.0	$426,823
38	4,426,291.0	4,426,293.0	$426,823
39	4,426,291.0	4,426,293.0	$426,823
40	4,426,291.0	4,426,293.0	$426,823
41	4,426,291.0	4,426,293.0	$426,823
42	4,426,291.0	4,426,293.0	$426,823
43	4,426,291.0	4,426,293.0	$426,823
44	4,426,291.0	4,426,293.0	$426,823
45	4,426,291.0	4,426,293.0	$426,823
46	4,426,291.0	4,426,293.0	$426,823
47	4,426,291.0	4,426,293.0	$426,823
48	4,426,291.0	4,426,293.0	$426,823
49	4,426,291.0	4,426,293.0	$426,823
50	4,426,291.0	4,426,293.0	$426,823

EFFECTS OF CONTROLS FOR STACK 8 FLUX STANDARD = 6
SCENARIO = 2 THICKNESS(in meters) = 1.021

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,248,388.0	0.0	$0
2	1,248,388.0	0.0	$0
3	1,248,388.0	0.0	$0
4	1,248,388.0	0.0	$0
5	1,248,388.0	0.0	$0
6	1,248,388.0	0.0	$0
7	1,248,388.0	0.0	$0
8	1,248,388.0	0.0	$0
9	1,248,388.0	0.0	$0
10	1,248,388.0	0.0	$0
11	1,248,388.0	0.0	$0
12	1,248,388.0	0.0	$0
13	1,248,388.0	0.0	$0
14	1,248,388.0	0.0	$0
15	1,248,388.0	0.0	$0
16	1,248,388.0	0.0	$0
17	1,248,388.0	0.0	$0
18	1,248,388.0	0.0	$0
19	1,248,388.0	0.0	$0
20	1,248,388.0	0.0	$0
21	1,248,388.0	0.0	$0
22	1,248,388.0	0.0	$0
23	1,248,388.0	0.0	$0
24	1,248,388.0	0.0	$0
25	1,248,388.0	0.0	$0
26	1,248,388.0	0.0	$0
27	1,248,388.0	0.0	$0
28	1,248,388.0	0.0	$0
29	1,248,388.0	0.0	$0
30	1,248,388.0	0.0	$0
31	1,248,388.0	0.0	$0
32	1,248,388.0	0.0	$0
33	1,248,388.0	0.0	$0
34	1,248,388.0	0.0	$0
35	1,248,388.0	0.0	$0
36	1,248,388.0	0.0	$0
37	1,248,388.0	0.0	$0
38	1,248,388.0	0.0	$0
39	1,248,388.0	0.0	$0
40	1,248,388.0	0.0	$0
41	1,248,388.0	0.0	$0
42	1,248,388.0	0.0	$0
43	1,248,388.0	0.0	$0
44	1,248,388.0	0.0	$0
45	1,248,388.0	0.0	$0
46	1,248,388.0	0.0	$0
47	1,248,388.0	0.0	$0
48	1,248,388.0	0.0	$0
49	1,248,388.0	0.0	$0
50	1,248,388.0	0.0	$0

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 9
SCENARIO = 2

FLUX STANDARD = 6
THICKNESS(in meters) = .533

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	2,041,902.0	0.0	$0
2	2,088,362.0	0.0	$0
3	2,136,292.0	0.0	$0
4	2,185,900.0	0.0	$0
5	2,237,451.0	0.0	$0
6	2,291,285.0	0.0	$0
7	2,347,873.0	0.0	$0
8	1,458,635.0	1,458,635.0	$4,910,701
9	1,458,635.0	1,458,635.0	$101,419
10	1,458,635.0	1,458,635.0	$101,419
11	1,458,635.0	1,458,635.0	$101,419
12	1,458,635.0	1,458,635.0	$101,419
13	1,458,635.0	1,458,635.0	$101,419
14	1,458,635.0	1,458,635.0	$101,419
15	1,458,635.0	1,458,635.0	$101,419
16	1,458,635.0	1,458,635.0	$101,419
17	1,458,635.0	1,458,635.0	$101,419
18	1,458,635.0	1,458,635.0	$101,419
19	1,458,635.0	1,458,635.0	$101,419
20	1,458,635.0	1,458,635.0	$101,419
21	1,458,635.0	1,458,635.0	$101,419
22	1,458,635.0	1,458,635.0	$101,419
23	1,458,635.0	1,458,635.0	$101,419
24	1,458,635.0	1,458,635.0	$101,419
25	1,458,635.0	1,458,635.0	$101,419
26	1,458,635.0	1,458,635.0	$101,419
27	1,458,635.0	1,458,635.0	$101,419
28	1,458,635.0	1,458,635.0	$101,419
29	1,458,635.0	1,458,635.0	$101,419
30	1,458,635.0	1,458,635.0	$101,419
31	1,458,635.0	1,458,635.0	$101,419
32	1,458,635.0	1,458,635.0	$101,419
33	1,458,635.0	1,458,635.0	$101,419
34	1,458,635.0	1,458,635.0	$101,419
35	1,458,635.0	1,458,635.0	$101,419
36	1,458,635.0	1,458,635.0	$101,419
37	1,458,635.0	1,458,635.0	$101,419
38	1,458,635.0	1,458,635.0	$101,419
39	1,458,635.0	1,458,635.0	$101,419
40	1,458,635.0	1,458,635.0	$101,419
41	1,458,635.0	1,458,635.0	$101,419
42	1,458,635.0	1,458,635.0	$101,419
43	1,458,635.0	1,458,635.0	$101,419
44	1,458,635.0	1,458,635.0	$101,419
45	1,458,635.0	1,458,635.0	$101,419
46	1,458,635.0	1,458,635.0	$101,419
47	1,458,635.0	1,458,635.0	$101,419
48	1,458,635.0	1,458,635.0	$101,419
49	1,458,635.0	1,458,635.0	$101,419
50	1,458,635.0	1,458,635.0	$101,419

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 10 FLUX STANDARD = 6
SCENARIO = 2 THICKNESS(in meters) = .333

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	241,192.0	277,992.9	$785,422
2	241,192.0	277,992.9	$24,004
3	241,192.0	277,992.9	$24,004
4	241,192.0	277,992.9	$24,004
5	241,192.0	277,992.9	$24,004
6	241,192.0	277,992.9	$24,004
7	241,192.0	277,992.9	$24,004
8	241,192.0	277,992.9	$24,004
9	241,192.0	277,992.9	$24,004
10	241,192.0	277,992.9	$24,004
11	241,192.0	277,992.9	$24,004
12	241,192.0	277,992.9	$24,004
13	241,192.0	277,992.9	$24,004
14	241,192.0	277,992.9	$24,004
15	241,192.0	277,992.9	$24,004
16	241,192.0	277,992.9	$24,004
17	241,192.0	277,992.9	$24,004
18	241,192.0	277,992.9	$24,004
19	241,192.0	277,992.9	$24,004
20	241,192.0	277,992.9	$24,004
21	241,192.0	277,992.9	$24,004
22	241,192.0	277,992.9	$24,004
23	241,192.0	277,992.9	$24,004
24	241,192.0	277,992.9	$24,004
25	241,192.0	277,992.9	$24,004
26	241,192.0	277,992.9	$24,004
27	241,192.0	277,992.9	$24,004
28	241,192.0	277,992.9	$24,004
29	241,192.0	277,992.9	$24,004
30	241,192.0	277,992.9	$24,004
31	241,192.0	277,992.9	$24,004
32	241,192.0	277,992.9	$24,004
33	241,192.0	277,992.9	$24,004
34	241,192.0	277,992.9	$24,004
35	241,192.0	277,992.9	$24,004
36	241,192.0	277,992.9	$24,004
37	241,192.0	277,992.9	$24,004
38	241,192.0	277,992.9	$24,004
39	241,192.0	277,992.9	$24,004
40	241,192.0	277,992.9	$24,004
41	241,192.0	277,992.9	$24,004
42	241,192.0	277,992.9	$24,004
43	241,192.0	277,992.9	$24,004
44	241,192.0	277,992.9	$24,004
45	241,192.0	277,992.9	$24,004
46	241,192.0	277,992.9	$24,004
47	241,192.0	277,992.9	$24,004
48	241,192.0	277,992.9	$24,004
49	241,192.0	277,992.9	$24,004
50	241,192.0	277,992.9	$24,004

EFFECTS OF CONTROLS FOR STACK 11　　FLUX STANDARD = 6
SCENARIO = 2　　THICKNESS(in meters) = .333

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	15,396,670.0	0.0	$0
2	15,747,700.0	0.0	$0
3	9,268,822.0	10,028,950.0	$23,536,680
4	9,268,822.0	10,028,950.0	$712,741
5	9,268,822.0	10,028,950.0	$712,741
6	9,268,822.0	10,028,950.0	$712,741
7	9,268,822.0	10,028,950.0	$712,741
8	9,268,822.0	10,028,950.0	$712,741
9	9,268,822.0	10,028,950.0	$712,741
10	9,268,822.0	10,028,950.0	$712,741
11	9,268,822.0	10,028,950.0	$712,741
12	9,268,822.0	10,028,950.0	$712,741
13	9,268,822.0	10,028,950.0	$712,741
14	9,268,822.0	10,028,950.0	$712,741
15	9,268,822.0	10,028,950.0	$712,741
16	9,268,822.0	10,028,950.0	$712,741
17	9,268,822.0	10,028,950.0	$712,741
18	9,268,822.0	10,028,950.0	$712,741
19	9,268,822.0	10,028,950.0	$712,741
20	9,268,822.0	10,028,950.0	$712,741
21	9,268,822.0	10,028,950.0	$712,741
22	9,268,822.0	10,028,950.0	$712,741
23	9,268,822.0	10,028,950.0	$712,741
24	9,268,822.0	10,028,950.0	$712,741
25	9,268,822.0	10,028,950.0	$712,741
26	9,268,822.0	10,028,950.0	$712,741
27	9,268,822.0	10,028,950.0	$712,741
28	9,268,822.0	10,028,950.0	$712,741
29	9,268,822.0	10,028,950.0	$712,741
30	9,268,822.0	10,028,950.0	$712,741
31	9,268,822.0	10,028,950.0	$712,741
32	9,268,822.0	10,028,950.0	$712,741
33	9,268,822.0	10,028,950.0	$712,741
34	9,268,822.0	10,028,950.0	$712,741
35	9,268,822.0	10,028,950.0	$712,741
36	9,268,822.0	10,028,950.0	$712,741
37	9,268,822.0	10,028,950.0	$712,741
38	9,268,822.0	10,028,950.0	$712,741
39	9,268,822.0	10,028,950.0	$712,741
40	9,268,822.0	10,028,950.0	$712,741
41	9,268,822.0	10,028,950.0	$712,741
42	9,268,822.0	10,028,950.0	$712,741
43	9,268,822.0	10,028,950.0	$712,741
44	9,268,822.0	10,028,950.0	$712,741
45	9,268,822.0	10,028,950.0	$712,741
46	9,268,822.0	10,028,950.0	$712,741
47	9,268,822.0	10,028,950.0	$712,741
48	9,268,822.0	10,028,950.0	$712,741
49	9,268,822.0	10,028,950.0	$712,741
50	9,268,822.0	10,028,950.0	$712,741

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 12
SCENARIO = 2

FLUX STANDARD = 6
THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	1,495,756.0	0.0	$0
2	1,495,756.0	0.0	$0
3	1,495,756.0	0.0	$0
4	1,495,756.0	0.0	$0
5	1,495,756.0	0.0	$0
6	1,495,756.0	0.0	$0
7	1,495,756.0	0.0	$0
8	1,495,756.0	0.0	$0
9	1,495,756.0	0.0	$0
10	1,495,756.0	0.0	$0
11	1,495,756.0	0.0	$0
12	1,495,756.0	0.0	$0
13	1,495,756.0	0.0	$0
14	1,495,756.0	0.0	$0
15	1,495,756.0	0.0	$0
16	1,495,756.0	0.0	$0
17	1,495,756.0	0.0	$0
18	1,495,756.0	0.0	$0
19	1,495,756.0	0.0	$0
20	1,495,756.0	0.0	$0
21	1,495,756.0	0.0	$0
22	1,495,756.0	0.0	$0
23	1,495,756.0	0.0	$0
24	1,495,756.0	0.0	$0
25	1,495,756.0	0.0	$0
26	1,495,756.0	0.0	$0
27	1,495,756.0	0.0	$0
28	1,495,756.0	0.0	$0
29	1,495,756.0	0.0	$0
30	1,495,756.0	0.0	$0
31	1,495,756.0	0.0	$0
32	1,495,756.0	0.0	$0
33	1,495,756.0	0.0	$0
34	1,495,756.0	0.0	$0
35	1,495,756.0	0.0	$0
36	1,495,756.0	0.0	$0
37	1,495,756.0	0.0	$0
38	1,495,756.0	0.0	$0
39	1,495,756.0	0.0	$0
40	1,495,756.0	0.0	$0
41	1,495,756.0	0.0	$0
42	1,495,756.0	0.0	$0
43	1,495,756.0	0.0	$0
44	1,495,756.0	0.0	$0
45	1,495,756.0	0.0	$0
46	1,495,756.0	0.0	$0
47	1,495,756.0	0.0	$0
48	1,495,756.0	0.0	$0
49	1,495,756.0	0.0	$0
50	1,495,756.0	0.0	$0

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 13
SCENARIO = 2

FLUX STANDARD = 6
THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	2,132,913.0	0.0	$0
2	2,132,913.0	0.0	$0
3	2,132,913.0	0.0	$0
4	2,132,913.0	0.0	$0
5	2,132,913.0	0.0	$0
6	2,132,913.0	0.0	$0
7	2,132,913.0	0.0	$0
8	2,132,913.0	0.0	$0
9	2,132,913.0	0.0	$0
10	2,132,913.0	0.0	$0
11	2,132,913.0	0.0	$0
12	2,132,913.0	0.0	$0
13	2,132,913.0	0.0	$0
14	2,132,913.0	0.0	$0
15	2,132,913.0	0.0	$0
16	2,132,913.0	0.0	$0
17	2,132,913.0	0.0	$0
18	2,132,913.0	0.0	$0
19	2,132,913.0	0.0	$0
20	2,132,913.0	0.0	$0
21	2,132,913.0	0.0	$0
22	2,132,913.0	0.0	$0
23	2,132,913.0	0.0	$0
24	2,132,913.0	0.0	$0
25	2,132,913.0	0.0	$0
26	2,132,913.0	0.0	$0
27	2,132,913.0	0.0	$0
28	2,132,913.0	0.0	$0
29	2,132,913.0	0.0	$0
30	2,132,913.0	0.0	$0
31	2,132,913.0	0.0	$0
32	2,132,913.0	0.0	$0
33	2,132,913.0	0.0	$0
34	2,132,913.0	0.0	$0
35	2,132,913.0	0.0	$0
36	2,132,913.0	0.0	$0
37	2,132,913.0	0.0	$0
38	2,132,913.0	0.0	$0
39	2,132,913.0	0.0	$0
40	2,132,913.0	0.0	$0
41	2,132,913.0	0.0	$0
42	2,132,913.0	0.0	$0
43	2,132,913.0	0.0	$0
44	2,132,913.0	0.0	$0
45	2,132,913.0	0.0	$0
46	2,132,913.0	0.0	$0
47	2,132,913.0	0.0	$0
48	2,132,913.0	0.0	$0
49	2,132,913.0	0.0	$0
50	2,132,913.0	0.0	$0

APPENDIX TO CHAPTER 9

EFFECTS OF CONTROLS FOR STACK 14
SCENARIO = 2

FLUX STANDARD = 6
THICKNESS(in meters) = .408

YEAR	EMISSIONS REMAINING AFTER CONTROLS (pCi/sec)	REDUCTION IN EMISSIONS DUE TO CONTROLS (pCi/sec)	ANNUAL COST
1	3,567,610.0	0.0	$0
2	2,213,060.0	2,213,060.0	$5,988,147
3	2,213,060.0	2,213,060.0	$154,915
4	2,213,060.0	2,213,060.0	$154,915
5	2,213,060.0	2,213,060.0	$154,915
6	2,213,060.0	2,213,060.0	$154,915
7	2,213,060.0	2,213,060.0	$154,915
8	2,213,060.0	2,213,060.0	$154,915
9	2,213,060.0	2,213,060.0	$154,915
10	2,213,060.0	2,213,060.0	$154,915
11	2,213,060.0	2,213,060.0	$154,915
12	2,213,060.0	2,213,060.0	$154,915
13	2,213,060.0	2,213,060.0	$154,915
14	2,213,060.0	2,213,060.0	$154,915
15	2,213,060.0	2,213,060.0	$154,915
16	2,213,060.0	2,213,060.0	$154,915
17	2,213,060.0	2,213,060.0	$154,915
18	2,213,060.0	2,213,060.0	$154,915
19	2,213,060.0	2,213,060.0	$154,915
20	2,213,060.0	2,213,060.0	$154,915
21	2,213,060.0	2,213,060.0	$154,915
22	2,213,060.0	2,213,060.0	$154,915
23	2,213,060.0	2,213,060.0	$154,915
24	2,213,060.0	2,213,060.0	$154,915
25	2,213,060.0	2,213,060.0	$154,915
26	2,213,060.0	2,213,060.0	$154,915
27	2,213,060.0	2,213,060.0	$154,915
28	2,213,060.0	2,213,060.0	$154,915
29	2,213,060.0	2,213,060.0	$154,915
30	2,213,060.0	2,213,060.0	$154,915
31	2,213,060.0	2,213,060.0	$154,915
32	2,213,060.0	2,213,060.0	$154,915
33	2,213,060.0	2,213,060.0	$154,915
34	2,213,060.0	2,213,060.0	$154,915
35	2,213,060.0	2,213,060.0	$154,915
36	2,213,060.0	2,213,060.0	$154,915
37	2,213,060.0	2,213,060.0	$154,915
38	2,213,060.0	2,213,060.0	$154,915
39	2,213,060.0	2,213,060.0	$154,915
40	2,213,060.0	2,213,060.0	$154,915
41	2,213,060.0	2,213,060.0	$154,915
42	2,213,060.0	2,213,060.0	$154,915
43	2,213,060.0	2,213,060.0	$154,915
44	2,213,060.0	2,213,060.0	$154,915
45	2,213,060.0	2,213,060.0	$154,915
46	2,213,060.0	2,213,060.0	$154,915
47	2,213,060.0	2,213,060.0	$154,915
48	2,213,060.0	2,213,060.0	$154,915
49	2,213,060.0	2,213,060.0	$154,915
50	2,213,060.0	2,213,060.0	$154,915

Appendix B:

Appendix B: Description Of The Trade Forecasting Model

9.B.1 Introduction

Many uncertainties exist in forecasting the supply and demand of WPPA. The model that was developed uses various supply, demand, and cost forecasts in an attempt to test the competitiveness of the United States phosphate industry over the next 30 years. The data used includes:

1) Plant specific cost and capacity data for 32 plants in the U.S., Morocco, Tunisia, Senegal, Israel, and Jordan. This data, from a study by Zellars-Williams, [ZE86] includes detailed production costs and supply forecasts until 2005. The regions of the world covered by this data include all regions that are significant net exporters of phosphoric acid and phosphate fertilizers.

2) A consumption forecast by region through 2010 by Wharton Econometric Forecasting Associates [WEFA88].

3) Freight forecasts by Zellars-Williams through 2005 from the major exporters to the major importers.

4) Alternative rock mining costs from a U.S. Bureau of Mines study by R. Fantel, William Stowasser and others [Fa85].

With the exception of WEFA's consumption forecast, all of the forecasts do not go beyond 2005. Therefore some limited assumptions were made to extend the forecasts to the year 2018. Various modifications to the data sources listed above were also necessary to reconcile the data sources. All of these modifications and the operation of the model are described below.

WPPA is sold in several different forms. Some countries purchase the acid and domestically produce various fertilizers, while other countries purchase finished fertilizers. For simplicity, the model focuses only on the comparative cost of producing phosphoric acid and does not consider the cost of producing specific fertilizers, such as diammonium phosphate and triple superphosphate.

The purpose of the model is to identify the low cost suppliers for each importing region over the next thirty years. The model considers six regions: Latin America, Western Europe, Eastern Europe, South Central Asia, East Asia, and Oceania. There are three exporting regions which are North America, Africa, and West Asia. Below is a description of the calculations made for the years 1985, 1990, 1995, 2000, 2005, and 2018.

9.B.2 Model Structure

The model begins by comparing the quantity of phosphoric acid each importing region needs to import to satisfy its demand and the cost of each exporting plant. The appropriate transportation cost is added into the plants' production cost to represent the final cost for that particular exporting country. The model ranks suppliers for each importing region, from the lowest to the highest cost supplier. The supply is then distributed in each region, beginning with the lowest cost supplier, until all demand is satisfied. In this way each supplier is assumed to maximize profits by first supplying those regions where its costs are the lowest.

Several alterations were made to the data that is used in the model. First, the Zellars-Williams supply forecast included Turkey in its Western Europe figures, whereas the WEFA consumption forecast included Turkey in its Asian figures. In addition, WEFA and Zellars-Williams organized Asian supply and demand differently. Section 9.B.3 describes how the data was modified.

WEFA's consumption figures were extended to 2018 by taking the 2010 figures and using the WEFA 1.9 percent annual growth rate forecast for consumption until 2010.

The Zellars-Williams supply forecast was extremely conservative, predicting increases only where firm plans had been announced at the time the forecast was made. As a result, many regions showed only very slight increases after 1995 despite highly favorable production conditions. Under Zellars-Williams' cautious supply forecast, world supply increases from 34 million metric tons in 1985 to 37 million in 1995 and drops to 34 million in 2005. In comparison, WEFA's consumption forecast increases from 33 million in 1985 to 38.5 in 1995 to 45.6 million in 2005. Zellars-Williams' consumption forecast is even higher, 59.8 million in 2005 [ZE86]. Consequently, Zellars-Williams' supply forecast was revised to increase at a rate comparable to the increase in world demand. More detail on the assumptions made in revising their supply estimates are given in section 9.B.4.

Production capacities and costs for individual phosphoric acid plants were taken from a Zellars-Williams' study [ZE86]. All United States plants were included except for two: Arcadian's plant in Geismar, Louisiana and Mississippi Chemical Co. plant in Pascagoula, Mississippi. Capacities for these two plants were obtained from the Tennessee Valley Authority, [TVA88] and their costs were assumed to be the same as those for Mobil's plant in Pasadena, Texas.

One Canadian plant was included in the Zellars-Williams' study, and a composite plant called Other Canada was added to represent all other Canadian production. Production capacity levels for Canada were also obtained from the Tennessee Valley Authority. These two plants are included only because all North American forecasts have Canada included in their figures.

Plant specific data was also available for Morocco, Tunisia, Senegal, Jordan, and Israel, which are the major non-U.S. exporting nations. Two composite plants -- Other Africa and Other West Asia -- were added which represent the sum of the additional supply from plants in that region. These composite plants are assumed to produce at the average cost for that region.

With some exceptions described in section 9.B.4, costs for all U.S. plants were projected out to 2018 from 2005 by continuing the rate of increase evident between 1985 and 2005. For non-U.S. plants in which costs were declining (in constant dollars) between 1985 and 2005, costs were assumed to remain the same as in 2005. This is reasonable because by 2005 the phosphate industries of non-U.S. exporters will have fully matured and learning curve economies and economies of scale will be achieved.

U.S. production capacities in 2018 were assumed to be the same as the Zellars-Williams forecasts for 2005. For specific plants in Zellars-Williams' projections, capacity increases before 2000 but beyond 2000 there are no increases or decreases. However, in Zellars-Williams' aggregate U.S. supply forecasts for the year 2005, Zellars-Williams' estimated capacity for North America falls to 8,906,000 metric tons of capacity, though their plant specific data indicates capacity would be 12,087,000 metric tons. It is likely that Zellars-Williams kept plant specific capacities at this higher level to avoid having to guess which plants might close by 2005. However, in their analysis they obviously expect some closures among U.S. plants.

The model was run under two different cost scenarios for plants located in the U.S. which obtain their rock from central Florida. In one case, costs were as forecasted by Zellars-Williams. In the other case, production costs were increased to reflect higher rock costs in Florida, beginning in 1995, as old low cost reserves become depleted and new, lower quality rock resources need to be developed. To estimate the phosphate rock costs from new resources, rock cost estimates were taken from a U.S. Bureau of Mines study by Stowasser, Fantel and Peterson which estimates the quantity of rock available within certain ranges of cost [Fa85]. The amount of rock needed in 2000 was calculated from the supply forecast for WPPA, and from this the rock price was estimated and applied to plants whose rock comes from the Central Florida pool. Some companies own phosphate rock reserves and active mines that will still be operating after 1995. Data was available from Zellars-Williams in many of these cases and Zellars-Williams' estimate of the cost to the company of mining its own rock was used.

The second scenario of the model allowed for significantly higher rock mining costs for a variety of U.S. plants. The U.S. plants were divided into two groups according to where their rock is supplied. Plants receiving rock from central Florida were given rock costs in line with the Stowasser study described earlier. The range of rock costs found in the Zellars-Williams cost data was maintained but each plant's rock costs were increased by a similar proportion so that the average rock costs corresponded to Stowasser's forecast. The exhaustion of cheaper rock begins in the 1995 period and the full costs are attributed by the year 2000. The higher rock costs were incorporated into the total WPPA costs by assuming 3.55 tons of rock are used per metric ton of WPPA produced.

9.B.3 Distribution of Exporters Total Supply

When distributing a plant's production among several regions, the model makes a few simple assumptions. First, if supplier X can competitively supply four different regions and, for example, X ranks third in all four regions, then each region receives an equal portion of supplier X's production. If supplier X then appears fourth on another region's ranking, that region will receive nothing from supplier X because X's production will have already been sold for that year.

In the non-U.S. net exporting regions, Africa and West Asia, domestic demand is assumed to be supplied by the many other plants in those countries for which plant specific costs are not available. Other excess capacity in those countries was assigned to composite plants called Other Africa or Other West Asia. The cost attributed to this other production is the average of all the individual costs for that region. This production is also available for export.

If supplier X is a non-U.S. producer, then all of its production will be exported.

For North America, a different assumption is made because cost data is available for all but two small plants, and supply is expected to fall rather than increase. In the case where supplier X is a U.S. plant and X is the third lowest cost supplier in four regions, the supply available from X is divided by 6, with one share going to each of the four importing regions, and two shares going to the U.S. market. The U.S. market always gets two shares, which assumes each producer continues to be actively involved in the large U.S. market. This assumption is consistent with American producer's past behavior.

9.B.4 Modifications to Zellars-Williams and WEFA Data

The Zellars-Williams supply forecast was altered so that Turkey appeared in its West Asia figures. Because Turkey has some indigenous phosphate rock supply, Turkey's supply was forecasted to decline at only half the rate of decline forecast for Western Europe. Turkey's supply was then subtracted from the Western European figure and added to the West Asia figure.

WEFA's consumption forecast included all of Asia in one figure, whereas Zellars-Williams divided Asia into East, West, and South Central. The following method was used to divide WEFA's Asian consumption forecast. First, Turkey's consumption was calculated by taking their 1985 consumption and using WEFA's annual growth rates to forecast their consumption. A growth rate of 2.1 percent was used through 1995 and 1.9 percent was used thereafter. Next, Turkey's consumption figures were added to Zellars-Williams' West Asia consumption figures. Third, the percent of total Asian consumption represented by each region of Asia was calculated using the Zellars-Williams consumption figures, which were constant for all of the forecasted years. These percentages were then applied to the WEFA Asian consumption forecasts to derive the final subdivided Asian consumption forecasts.

As explained earlier, Zellars-Williams' supply forecast was modified to allow for new plant construction that has not already been announced. Special attention was given to how the new supply was distributed among existing producing countries. The regional trends in production levels identified by Zellars-Williams between 1985 and 1990 were projected to continue in future years. Had the rate of growth between 1985 and 1990 been used, however, an unrealistically high supply level would have been forecasted. Instead, the WEFA projected rate of growth of demand was used. This assumes that, in the long run, supply and demand will grow at the same rate. Those regions experiencing growth in capacity between 1985 and 1990 were assumed to continue to have high rates of growth in the coming decade. These countries, such as Morocco, are also the countries that have substantial demonstrated phosphate rock reserves. The specific steps to calculate each region's supply are described below:

1) The increase in world supply between 1985 and 1990 was estimated and each region was allocated its proportion of that supply. As in: (A-B)/C; where:

A=1990 regional forecast.
B=1985 regional forecast.
C=Net new world supply between 1985 and 1990.

2) The world supply of phosphoric acid after 1990 was estimated by using a 2.1 percent annual growth rate until 1995 and 1.9 percent thereafter.

CHAPTER 10

COAL-FIRED BOILERS

10. COAL-FIRED BOILERS

10.1 Introduction and Summary

On November 8, 1979 the Environmental Protection Agency listed radionuclides as a hazardous air pollutant under the provisions of section 112 of the Clean Air Act. Subsequently, EPA investigated the necessity of regulating coal-fired boilers in the utility and industrial sectors. These two types of boilers account for approximately 90 percent of the heat generated by burning coal. The remaining 10 percent is generated by residential and commercial boilers for the purpose of space and water heating. For this analysis, only coal-fired utility and industrial boilers will be considered.

The coal used to fire boilers contains radionuclides and their daughter products which are not destroyed during combustion. Instead, the radionuclides attach themselves to particulate emissions and are either removed from the exhaust with control devices or released into the air.

Currently, there are no Federal or state regulations specifically limiting the emissions of radionuclides from coal-fired industrial boilers. However, air emissions from coal-burning facilities are regulated by state and Federal guidelines designed to meet the ambient standards set forth by the Federal Clean Air Act. These standards affect several pollutants emitted by coal-burning facilities, in particular particles 10 microns or less in diameter (PM10), sulfur dioxide, oxides of nitrogen, CO and lead (40 CFR 50.6, 50.7, 50.8, 50.11, 50.12). Emissions of radionuclides are positively correlated to emissions of particulate matter; therefore, regulations governing particulate matter emissions also control radionuclide emissions. These regulations include: the PM10 ambient standard, prevention of significant deterioration, new source performance standards, and state air quality implementation plans.

10.2 Industry Profile

The main function of large coal-fired boilers in the utility sector is the generation of electricity. Industry, however, depends upon coal-fired boilers for the production of process steam, space heating, and other industrial purposes. Information on utility boilers is far more complete, accurate, and accessible than that on industrial boilers. The furnaces and coal used by both sectors, and therefore the emissions created, are highly similar. There are, however, some differences in the boilers used.

10.2.1 Demand

In 1982, approximately 20 percent of the United States' energy needs were met by burning coal. Of the coal used, 74 percent was used to generate electricity and 24 percent was used by industry for purposes other than the generation of electricity [EIA85]. For both industrial and utility applications bituminous, sub-bituminous, and lignite coals are used more often than anthracite coal. Although natural gas, oil, and nuclear fission can be used to generate electricity, the combined use of these energy sources in the generation of electricity has declined in recent years. It is expected that coal will supply more than half of the electricity generated in the United States in the foreseeable future.

10.2.2 Supply

On average, the United States coal mines provide more than 16 million tons of coal per week. This amount fluctuates greatly, ranging from 20 million tons per week to less than 10 million. Coal production can decrease for a variety of reasons, ranging from weather to miners' strikes and vacations [EIA87].

The three primary coal producing regions in the United States are the western, interior, and Appalachian regions. In 1985, in terms of quantity of coal produced, the Appalachian region was the most productive, followed by the western and interior regions. In that year, the Appalachian region produced 427.2 million short tons of coal, valued at 13.8 billion dollars. The western region produced 268.7 short tons of coal at a value of 3.9 billion dollars. Coal production in the interior region in 1985 was 187.8 million short tons valued at 4.6 billion dollars [EIA87].

10.2.3 Industry Structure and Profile

In 1986, there were approximately 1200 coal-fired utility boilers in the United States, with a net generating capacity of 305 giga-watts (GW) [EIA85]. There are three types of power plants designed to operate and serve three load classes: base load, intermediate load, and peaking plants. Base load power plants operate near full capacity most of the time. Intermediate load plants operate at varying levels of capacity each day. Finally, peaking plants operate only during periods of high demand, about 700-800 hours a year. Coal-fired utility boilers are primarily used in base and intermediate load plants. Coal is rarely the primary fuel for a peaking plant.

There are three general types of coal-firing utility boilers: stoker furnaces, cyclone furnaces, and pulverized-coal furnaces. Stoker furnaces are usually small, older boilers ranging in capacity from 7.3 to 73 mega-watts (MW). Stoker furnaces require about 3.3 kg of coal per kilowatt-hour and are less efficient than furnaces handling pulverized coal. Cyclone furnaces are high temperature combustion chambers for burning crushed coal. As of 1974, only 9 percent of the coal-fired utility boiler capacity was of the cyclone type, and no boilers of this kind have been ordered by utilities in the past seven years [Co75]. Pulverized coal furnaces burn coal that has been pulverized to a fine powder. A carefully proportioned mixture of pulverized coal and air is injected into the combustion zone. The pulverized coal-fired boiler is now the most prevalent type of coal-burning unit in the utility sector. There are two types of pulverized coal-fired boilers; dry bottom and wet bottom. Dry bottom are the most prevalent, with 76 percent of the coal-firing utility boilers being of this type. Of the remaining coal-firing utility boilers, 11 percent are pulverized wet bottom, 11 percent are cyclone, and 2 percent are stoker. The amount and type of residue produced when coal is burned differs with the type of furnace and coal used. As coal is burned, the minerals in the coal melt and condense into a glass-like ash; the quantity of ash depends upon the mineral content of the coal. A portion of the ash settles to the bottom of the boiler, bottom ash, and the remainder enters the flue, fly ash. The distribution between bottom ash and fly ash depends upon the firing method, the ash fusion temperature of the coal, and the type of boiler bottom, wet or dry. Table 10-1 displays the percent of fly and bottom ash produced by various types of coal and furnaces.

Coal-fired industrial boilers are used primarily to produce process steam, generate electricity for the industry's on-site use, and provide space and water heat. Boilers are used in almost all industries; however, the primary users are smelters, steel, aluminum, and copper manufacturers, pulp and paper manufacturers, and the chemical industry. There are three main types of boilers used in the industrial sector. These are: water tube, fire tube, and cast iron. Water tube boilers heat the water to a high-pressure, high-temperature steam by passing the water through tubes which are heated externally by contact with high combustion gases. Fire tube and cast iron boilers heat the water by transferring heat from the hot gases inside the tubes to circulating water outside the tubes. The only difference between the two types is that cast iron is used in the construction of the tubes instead of steel which is used in fire tube boilers. Table 10-2 displays the number and capacity of industrial boilers in the United States. There are two main types of furnaces used for industrial coal-fired boilers. These are the pulverized coal furnace and the stoker furnace, as described in the previous text.

Table: 10-1: Coal Ash Distribution by Boiler Type.

	Percent Fly Ash/Percent Bottom Ash		
Furnace Type	**Bituminous**	**Lignite**	**Anthracite**
Pulverized Dry Bottom	80/20	35/65	85/15
Pulverized Wet Bottom	65/35	———	———
Cyclone	13.5/86.5	30/70	———
Stoker	60/40	35/65	5/95

SOURCE: [Me86]

Table 10-2: Numbers and Capacities of Industrial Boilers.

	Unit Capacity (MW Thermal Input)				
Boiler Type	0-3	3-15	15-30	30-75	>75
Water Tube Units	683	2,309	1,290	1,181	423
Total MW	835	22,225	27,895	50,825	59,930
Fire Tube Units	8,112	1,224			
Total MW	5,650	7,780			
Cast Iron Units	35,965				
Total MW	6,330				

SOURCE: [EPA81]

10.3 Current Emissions, Risk Levels, and Feasible Control Methods

10.3.1 Introduction

Coal contains mineral matter, including small quantities of naturally occurring radionuclides. The radionuclides of primary interest are uranium-238 and thorium-232 as well as their decay products, Po-210 and Pb-210. Table 10-3 shows the uranium and thorium content in different types of coal. In addition to the concentration of mineral matter, several other factors have substantial influence upon the harmful emissions from coal-fired boilers. These factors include furnace design, capacity, heat rate, and ash partitioning. Ash partitioning, or the proportion of ash that is fly ash versus bottom ash, is a function of the firing method, type of coal, and type of furnace used.

10.3.2 Current Emissions and Estimated Risk

Measurements have shown that certain radionuclides are partitioned unequally between bottom and fly ash [Be78, Wa82]. One explanation for this phenomenon is that certain elements are preferentially concentrated on the particle surfaces, resulting in their depletion in the bottom ash and their enrichment in the fly ash [Sm80]. The highest concentration of the trace elements in fly ash is found in .5 to 10 micrometer diameter particulates, the size range that can be inhaled and deposited in the lung. These fine particles are less effectively removed by particulate control devices than larger particles. Uranium is enriched in fly ash relative to bottom ash, particularly in particles less than 1 micron in diameter. Thorium, however, shows virtually no small particle enrichment and is only slightly enriched in fly ash.

10.3.3 Control Technologies

The National Ambient Air Quality Standards require air emission controls for virtually all coal-fired utility boilers in the United States. There are four types of conventional control devices commonly used for control of particulate matter in utility boilers: electrostatic precipitators (ESP), mechanical collectors, wet scrubbers, and fabric filters. Particulate emissions from industrial boilers are controlled by similar devices. In theory, ESP, wet scrubbers, and fabric filters are all capable of greater than 99.8 percent collection efficiencies for ash as small as one micron in diameter. At present, almost all collectors are at least 98 percent efficient during normal operation.

Table 10-3: Typical Uranium and Thorium Concentrations in Coal.

Region/ Coal Rank	Uranium Range (ppm)	Uranium Geometric mean (ppm)	Thorium Range (ppm)	Thorium Geometric mean (ppm)
Pennsylvania				
Anthracite	0.3-25	1.2	1.4-2.8	4.7
Appalachian				
Bituminous	<0.2-11	1.0	2.0-48	2.8
NR	0.4-3	1.3	1.8-9	4.0
Bituminous	NR	1.1	NR	2.0
Bituminous	0.1-19	1.2	NR	3.1
Illinois Basin				
NR	0.3-5	1.3	0.5-0.7	1.9
Bituminous	0.2-43	1.4	<3-79	1.6
Bituminous	0.2-59	1.7	0.1-79	3
Northern Great Plains				
Bituminous Subbituminous	<0.2-3	0.7	<2-8	2.4
Subbituminous	<0.1-16	1.0	0.1-42	3.2
Lignite	0.2-13	1.2	0.3-14	2.3
Western				
NR	0.3-3	1.0	0.6-6	2.3
Rocky Mountain				
Bituminous Subbituminous	0.2-24	0.8	<3-35	2.0
Subbituminous	0.1-76	1.9	0.1-54	4.4
Bituminous	0.1-42	1.4	<0.2-18	3.0
All Coals	<0.1-76	1.3	<0.1-79	3.2

Note: 1ppm uranium-238 is equivalent to 0.33 pCi/g of coal.
1ppm thorium-232 is equivalent to 0.11 pCi/g of coal.

NR - Not reported.

SOURCE: [EPA88]

The risk assessment of utility boilers is based on reference (actual) facilities selected to represent large and typical utility boilers. The reference facilities were selected from a data base of almost one thousand utility boilers maintained by the EPA's Office of Air Quality Planning and Standards (OAQPS). The boilers in the data base account for virtually all of the coal used by utility boilers. The risk assessment of industrial boilers is based on a single reference plant. The reference plant has the largest estimated release of total particulates of the industrial boilers in OAQPS' data base of about 500 industrial boilers [EPA89]. The coal-fired industrial boilers in the OAQPS data base represent a stratified random sample of more than 2,000 industrial boilers located throughout the United States. In selecting the reference utility boilers, the boilers in the data base were classified according to the number of persons living within 50 kilometers of the plant. Urban plants were defined as having 3,000,000 persons or more, suburban plants as having 800,000 to 3,000,000 persons, rural plants as having 100,000 to 800,000 persons, and remote plants as having less than 100,000 persons. This classification shows 34 utility boilers located in urban areas, 234 located in suburban areas, 567 located in rural areas, and 150 located in remote areas. For each location, the large reference plant and the typical reference plant were chosen based on the estimate of total particulate emissions. The large reference plants were used in the evaluation of the risks to nearby individuals and the typical reference plants were used to evaluate the magnitude and distribution of the population risk. Tables 10-4 and 10-5 give a summary of U-238 and Th-232 emission factors by coal-fired utility boiler type and control technique.

10.4 Analysis of Benefits and Costs

10.4.1 Introduction

As already mentioned, there are currently several state and Federal regulations regarding the emissions from coal-fired boilers. Therefore, any cost-benefit analysis would be of further specific regulations and more stringent controls. In order to determine the amount of further regulations necessary, the radionuclide related risks from coal-fired emissions must first be assessed. Several assumptions were made in carrying out risk calculations in order to lend conservatism to the results. Food input parameters were computed for the food growing capabilities of each population category. For urban and remote utility boilers it was assumed that individuals residing in the fallout region of these plants also supplied all of their own meat and milk. In the case of suburban utilities, it was assumed that half of the ingested fruit and vegetables were grown at home and that the remainder of the fruits and vegetables as well as the meat and milk were supplied regionally. For urban utilities, it was assumed that everything was supplied regionally and nothing was grown at home.

Table 10-4: U-238 Emission Factors for Coal-Fired Utility Boilers.

Boiler Type/ Control	Emission Factor Average (pCi/g)	Emission Factor Range (pCi/g)	Emission Factor Average (pCi/MBTU)	Emission Factor Range (pCi/MBTU)
Pulverized Dry Bottom				
ESP	6.55	3.3-9.2	295.3	6.3-675.9
ESP/Scrubber	7.1	-	22.5	-
Scrubber	5.6	-	73.7	-
Pulverized Slag Bottom				
Mechanical/ESP	0.004	-	-	-
Cyclone				
ESP	1.5	0.005-3.0	68.0	
Scrubber	13.9	0.017-37.5	1757.8	301.2-3214.3
Stoker				
Fabric Filter	0.003	-	-	-
ESP	0.5	-	-	-
Unspecified				
ESP	16.1	7-34.2	294	101.6-486.5

MBTU = million BTU.

SOURCE: [Me86]

Table 10-5: Th-232 Emission Factors for Coal-Fired Utility Boilers.

	Emission Factor		Emission Factor	
Boiler Type/ Control	**Average (pCi/g)**	**Range (pCi/g)**	**Average (pCi/MBTU)**	**Range (pCi/MBTU)**
Pulverized Dry Bottom				
ESP	3.0	0.6-5.3	170.0	50.3-180.7
ESP/Scrubber	7.14	-	22.7	-
Scrubber	2.78	-	36.5	-
Cyclone				
ESP	1.8	-	40.8	-
Scrubber	2.09	1.5-2.68	170.0	110.2-229.7
Stoker				
ESP	0.5	-	13.8	-

MBTU = million BTU.

SOURCE: [Me86]

10.4.2 Least-Cost Control Technologies

Selection of particulate control devices for a particular utility is a function of several variables, including boiler capacity, boiler type, inlet loading, fly ash characteristics, and inlet particle size distribution. Virtually all coal-fired utility boilers in the United States are required to have air emission controls in order to meet National Air Quality Standards (NAAQS). The least costly option for increased control of radionuclide emissions is continued reliance on on-going measures taken to conform to clean air act requirements for NAAQS and the precursors of acid rain. These tend to be updated as new technologies become available. For example, the recent development of highly temperature resistant fabrics has resulted in the increased use of fabric filters in the reduction of boiler emissions. However, increased efficiency of control technologies will be expensive because the current technologies comprised mainly of electrostatic precipitators (ESP), mechanical collectors, wet scrubbers, and fabric filters are now at least 98 percent effective during normal operation.

10.4.3 Health and Other Benefits

Table 10-6 shows the estimated radiation dose rates from large coal-fired utility boilers for each population category. Similar data is displayed in Table 10-7 for a reference coal-fired industrial boiler. Tables 10-8 and 10-9 show the estimated distribution of the fatal cancer risk to the regional populations from all coal-fired utility and industrial boilers.

10.4.4 Estimates of Benefits and Costs

Existing boilers can be retrofitted with additional electrostatic precipitators to reduce emissions to the level prescribed for new sources (13 ng/J). Although a full evaluation of supplementary control options and costs has not been performed for industrial boilers; it is known that existing boilers could be retrofitted with ESPs. It is estimated that retrofitting ESPs at industrial boilers with heat inputs over 2E+6 MBTU/hr would reduce particulate emissions by a factor of two. The cost and health benefits are not known. With all coal-fired utility boilers operating with particulate emissions of 13 ng/J (0.03 lb/MBTU) of heat input, the current 12,500 million MBTU annual heat input would result in about 0.17 billion kg of particulate releases. The source term and potential health impact would therefore be reduced by about a factor of two. The estimate of the total deaths per year would drop to 0.2. The EPA's office of Air Quality Planning and Standards has estimated the costs of retrofitting all existing utility coal-fired boilers to meet the control level of 13ng/J to be about $13 billion in capital costs (1982 dollars) and about $3.4 billion in annual costs [RC83].

Table 10-6: Estimated Radiation Dose Rates from Large Coal-Fired Utility Boilers.

Facility	Organ	Nearby Individuals (mrem/y)	Regional Population (person-rem/y)
Remote	Bone Surface	1.1E+0	2.9E+1
	Remainder	3.1E-1	4.4E+0
	Gonads	2.7E-1	3.1E+0
	Red Marrow	2.7E-1	---
	Lung	---	1.6E+1
Rural	Bone Surface	1.2E+1	3.9E+1
	Remainder	2.1E+0	5.6E+0
	Red Marrow	1.5E+0	4.2E+0
	Gonads	1.0E+0	2.0E+0
	Lung	---	6.6E+0
Suburban	Gonads	5.2E-1	5.3E+0
	Breast	4.9E-1	---
	Remainder	4.1E-1	9.2E+0
	Red Marrow	4.0E-1	7.9E+0
	Lung	4.0E-1	1.9E+1
	Bone Surface	---	5.9E+1
Urban	Gonads	3.5E-1	6.8E+0
	Breast	3.2E-1	---
	Remainder	2.7E-1	9.6E+0
	Red Marrow	2.7E-1	---
	Lung	2.6E-1	3.7E+1
	Bone Surface	---	6.5E+1

SOURCE: [EPA88]

Table 10-7: Estimated Radiation Dose Rates from the Reference Coal-Fired Industrial Boiler.

Organ	Nearby Individuals (mrem/y)	Regional Population (person-rem/y)
Bone Surface	6.5E+0	5.6E+1
Remainder	9.0E-1	5.8E+0
Red Marrow	6.1E-1	----
Lung	----	2.1E+1

SOURCE: [EPA88]

Table 10-8: Estimated Distribution of the Fatal Cancer Risk to the regional (0-80km) populations from all Coal-Fired Utility Boilers.

Risk Interval	Number of Persons	Deaths/y
1E-1 to 1E+0	0	0
1E-2 to 1E-1	0	0
1E-3 to 1E-2	0	0
1E-4 to 1E-3	0	0
1E-5 to 1E-4	0	0
1E-6 to 1E-5	1.3E+5	1E-3
Less than 1E-6	2.4E+8	4E-1
Totals	2.4E+8	4E-1

SOURCE: [EPA88]

Table 10-9: Estimated Distribution of the Fatal Cancer Risk to the regional (0-80km) populations from all Coal-Fired Industrial Boilers.

Risk Interval	Number of Persons	Deaths/y
1E-1 to 1E+0	0	0
1E-2 to 1E-1	0	0
1E-3 to 1E-2	0	0
1E-4 to 1E-3	0	0
1E-5 to 1E-4	0	0
1E-6 to 1E-5	*	*
Less than 1E-6	2.4E+8	4E-1
Totals	2.4E+8	4E-1

---

* The results of the risk assessment of the model facility indicate that there may be individuals in this risk interval. However, data are insufficient to provide quantitative estimates.

SOURCE: [EPA88]

Figures published in the Federal Register predict the capital costs to utilities of retrofitting existing coal-fired boilers to meet Clean Air Act requirements pertaining to criteria air pollutants to be slightly higher. Capital improvement costs are estimated to be approximately $15 billion and the subsequent operating costs are estimated to be approximately $3 billion a year [FR83].

REFERENCES

Be78 Beck, H.L., *Perturbation of the Natural Radiation Environment Due to the Utilization of Coal as an Energy Source*, Proceedings, DOE/UT Symposium on the Natural Radiation Environment, Houston, TX, 1978.

Co75 Cowherd, C. et al., *Hazardous Emission Characteristics of Utility Boilers*, NTIS PB-245-915, 1975.

EIA85 Energy Information Agency, Department of Energy, *Annual Energy Outlook*, 1985, Washington, D.C.

EIA87 Energy Information Agency, Department of Energy, *Coal Data: A Reference*, Washington, D.C.; March 1987, page 14.

EPA81 Environmental Protection Agency, *The Radiological Impact of Coal-fired Industrial Boilers*, EPA, Office of Radiation Programs, Washington, D.C., (Draft Report), 1981.

EPA88 *Risk Assessments*, Vol. 2.EPA88

EPA89 U.S. Environmental Protection Agency, "Coal and Oil Combustion Study: Summary and Results," draft report in preparation, Office of Air Quality, Planning and Standards, Research Triangle Park, NC, scheduled for publication during 1989.

FR83 *Federal Register*, Volume 48 Number 67, April 6, 1983, page 15085, 15086.

Me86 Mead, R.C., B.K. Post, and G.W. Brooks, "Summary of Trace Emissions from, and Recommendations of Risk Assessment Methodologies for Coal and Oil Combustion Sources", Radian No. 203-024-41, Radian Corporation, Research Triangle Park, N.C., 1986.

RC83 Radian Corporation, *Boiler Radionuclide Emissions Control: The Feasibility and Costs of Controlling Coal-Fired Boiler Particulate Emissions*, Prepared for the Environmental Protection Agency, January 1983.

Sm80 Smith, R.D., *The Trace Element Chemistry of Coal During Combustion and the Emissions from Coal-Fired Plants*, Progress in Energy and Combustion Science 6, 53-119, 1980.

Wa82 Wagner P. and Greiner N.R., Third Annual Report, *Radioactive Emissions from Coal Production and Utilization*, October 1, 1980-September 30, 1981LA-9359-PR, Los Alamos National Laboratory, Los Alamos, N.M., 1982.

CHAPTER 11

NRC-LICENSED FACILITIES AND NON-DOE FEDERAL FACILITIES

11. NRC-LICENSED FACILITIES AND NON-DOE FEDERAL FACILITIES

11.1 Introduction and Summary

This chapter covers Nuclear Regulatory Commission (NRC) licensed facilities that are not part of the nuclear fuel cycle and federal facilities using radionuclides other than those owned or operated by the Department of Energy (DOE). DOE facilities are discussed in chapters 6 and 7. The NRC and the Agreement States licensees are classified into by-product, source material, and special nuclear material categories. For purposes of this evaluation, these source categories are analyzed on the basis of nine sub-categories:

- Hospitals,
- Radiopharmaceutical manufacturers,
- Research laboratories,
- Research reactors,
- Sealed source manufacturers,
- Non-LWR fuel fabricators,
- Source material licensees,
- Low-level waste incinerators, and
- Non-DOE Federal facilities.

The approximately 6,000 facilities which fall into these categories are located in 50 states. The largest group consists of approximately 3,680 hospitals, which are licensed to handle radiopharmaceuticals. The next largest group consists of about 1,500 research laboratories. The information used for this evaluation was derived from literature search and review, and direct contact with the licensees and the NRC. After developing information on the emissions for each facility or facility class, an assessment was performed of the radiation dose and risk to the nearby and regional populations. If the assessment resulted in a significant predicted risk, then supplementary control options and costs were evaluated. Only two of the nine sub-categories warranted analysis of supplementary controls after the assessment of risks was conducted. The combined risk for all nine sub-categories is 2E-1 fatal cancers per year. The individual risk is also quite low, with all but two of the facilities resulting in doses of less than 1 mrem/yr to the nearby resident.

11.2 Industry Profile

Due to the large number and variety of sources, it is not feasible nor useful to develop a detailed industry profile. A brief description of each sub-category follows. Over half of the hospitals in the United States handle radiopharmaceuticals [AHA86]. The most prevalent use is for radionuclide imaging to aid in diagnosis of diseases. A smaller number of hospitals also use radionuclides for therapeutic purposes. Two-thirds of hospitals using therapeutic amounts of radiopharmaceuticals are located in urban areas.

Radiopharmaceutical manufacturers, which number about 120, fall into three sub-categories. There are 15 large firms which manufacture the pharmaceuticals, 70 small- to medium-sized firms which alter the chemical form of the nuclides, and 35 nuclear pharmacy operators which repackage the material into convenient quantities for distribution.

There are approximately 1,500 research laboratories which use radionuclides in unsealed forms. Over half of these laboratories are associated with academic institutions and the remainder with government or private research facilities [CEN81,BAT83,NRC88]. The academic laboratories frequently involve a large number of release points within a generalized area and use small amounts of a large number of radionuclides. Twenty-nine radionuclides were identified as in use. One use of radioactively-labeled chemicals is to trace dynamic processes.

There were 70 research and test reactors operating as of December, 1987. These reactors range in power level from zero to 10,000 kilowatts and are generally operated by universities for use in teaching and research. Although there are a number of different designs, the most common is the General Atomics TRIGA reactor.

Sealed-source manufacturers take radionuclides in unsealed form and put them into permanently sealed containers. There are two sub-categories of sealed source manufacturers - those that seal tritium gas into self-luminous lights (three manufacturers) and those who utilize other radiation sources (eight manufacturers which release more than exempt quantities of radionuclides).

Four facilities fabricate uranium fuel for research reactors or naval propulsion reactors. The process is similar to that used in the uranium fuel cycle, whereby enriched UO_2 is formed into pellets which are stacked inside tubes and then bundled into fuel assemblies.

Twelve NRC-licensed facilities were identified that handle relatively large amounts of thorium or non-enriched uranium during the manufacture of a product. Nine of these facilities are currently using thorium [Mo88]. An equal number of facilities are also licensed by the Agreement States. The processes used by these facilities are varied and may include processing lower thorium-content alloys into wire for lighting products, as well as scrap collection, glass production, and lens coating.

Airborne effluents are also produced by the incineration of low-level waste, primarily from hospitals and research laboratories. It is estimated that there are about 100 incinerators in the United States.

The Non-DOE Federal facilities are composed of two groups of Department of Defense facilities -- thirteen nuclear shipyards and naval bases and two unlicensed research reactors located at Aberdeen, Maryland and White Sands, New Mexico.

11.3 Current Emissions, Risk Levels, and Feasible Control Methods

11.3.1 Introduction

Due to the large number and variety of sources in this category, only a general description will be provided here as to the nature of the emissions, how the risks were estimated, and feasible control methods. Detailed descriptions and data can be found in the supporting documentation cited in the references below. The individual sub-category and total risks for both the nearby and regional populations are found in Table 11-1. These fatal cancer risks are estimated using assumptions concerning the facility emissions and release point characteristics, the proximity of nearby individuals, the meteorology for the sites, and estimates of organ exposures in mrem/yr, resulting in estimated risks of fatal cancer for both nearby and regional populations.

11.3.2 Current Emissions and Estimated Risk Levels

Emissions data for the hospitals were derived from a survey of over 100 facilities and were used to create a model facility [CRC87]. The primary emissions are xenon and iodine, and the emission rates range from 0.01 to 1.0 Ci/yr. The estimated risks were calculated for both urban and rural settings and multiplied by the number of facilities of each type to generate a total risk of 6E-2 deaths per year (d/yr).

The emissions for the radiopharmaceutical suppliers are based on data received directly from four suppliers, including effluent data reported to the NRC for a nuclear reactor. Almost all the risk is

Table 11-1 NRC Licensed and Non-DOE Facilities
Fatal Cancers Per Year

Category	No. of Facilities	Fatal Cancers (d/yr)
Hospitals	3680	6E-2
Radiopharmaceutical Manufacturers	120	2E-2
Research Laboratories	1500	8E-3
Research Reactors	70	4E-2
Sealed Source Manufacturers	11	2E-2
Non-LWR Fuel Fabricator	4	2E-4
Source Material Licensee	12	1E-3
Low-level Waste	100	1E-3
Non-DOE Federal Facilities	15	1E-3
TOTAL	6000	2E-1

accounted for by the facility that operates the nuclear reactor. The total risk is obtained by summing the risks from all sixteen facilities, and is estimated to be 2E-2 d/yr.

Emissions data were gathered from 46 research laboratories and compared to information from other available sources [BAT83, CRC87]. Approximately forty-one percent of all laboratories have emissions that are either zero or below the lower limits of detection of their monitoring equipment. A model facility was developed using a weighted average of the remaining facilities by type and multiplying by the number of facilities (622) having non-zero emissions. The total risk is estimated to be 8E-3 d/yr.

Emissions data were collected for the four largest emitters among research and test reactors. The resulting risks were extrapolated to the entire population based upon the contribution of the four largest emitters to the total emissions. The ratio was calculated based on Ar-41 emissions which were found to be fifty-nine percent of the total emissions for this sub-category. The total risk is estimated to be 4E-2 d/yr.

A model sealed source facility was estimated based upon the average emissions of four non-tritium manufacturers. Kr-85 is released in curie amounts and Co-60, Am-241, Ir-192, and Cf-252 in microcurie amounts. The tritium lighting producers all submitted information on their effluents so these data were used directly with site-specific information on meteorology. The total risk of 2E-2 d/yr is equal to the sum of the estimated doses from the three lighting facilities and the product of the total emissions of the model facility and the total number of facilities.

Operating reports were used for the emissions from non-LWR fuel fabricators. U-234 and U-235 are the nuclides which make the largest contribution to dose. Actual site characteristics, facility data, and local meteorological data were utilized. Total risk for this category is estimated to be 2E-4 d/yr.

Two reference facilities to represent source material licensees were used for the estimate of thorium and uranium emissions and their associated risks. The risk was obtained by multiplying the results by the number of facilities in this category. The total risk for this category is estimated to be 1E-3 d/yr.

Effluent data for 35 incinerators are available from a survey for the estimate of emissions from low-level waste [CRC87]. A model facility was created based upon these data. Data for the largest emitter was also modified. The model facility is estimated to result in 1E-5 fatal cancers per year, while the maximum emitter is estimated to result in 2E-4 fatal cancers per year. The total risk for this category, obtained by scaling up the risks from the model facility by a factor of 100, is estimated to be 1E-3 d/yr.

With respect to non-DOE federal facilities, a single model, was used to represent both Naval shipyards and the two non-licensed research reactors in Maryland and New Mexico. The model was based on emissions measured at the shipyards. Effluent monitoring at Department of Defense shipyards and bases reveals few measurable radionuclide releases [Ma88]. The Navy estimates maximum releases of noble gases to be 0.01 - 0.4 Ci/yr and of Co-60, 0.001 Ci/yr. An actual West-coast shipyard was used as the model facility to estimate the risks based upon the above emission rates. The risks from all DOD facilities is estimated to be 1E-3 d/yr.

The calculated risks summarized above are combined to provide an estimated baseline risk for the active category of 2E-1 d/yr. The sub-category with the largest collective risk is hospitals.

11.3.3 Control Technologies

Depending upon the effluent stream type and characteristics, various emission control technologies are currently in use. The most frequently used control systems consist of high efficiency particulate air (HEPA) filters. These control devices are used by hospitals, radiopharmaceutical suppliers, laboratories, sealed-source manufacturers, fuel fabricators, source material licensees, and non-DOE federal facilities. Charcoal filters are used to capture iodine, decay traps are used to hold radioactive gases until the short-lived products decay, desiccant columns are used by lighting manufacturers to remove tritium, and one facility has installed a catalytic recombiner to convert tritium gas to tritiated water. Waste incinerators utilize afterburners, venturi scrubbers, and gas scrubbers to remove pollutants. Fuel fabricators are known to use gas scrubbers as well.

Only two of the nine sub-categories are estimated to have a high enough dose and resulting risk level to warrant further evaluation of supplementary controls. For the sub-category of hospitals, it is not possible to accurately estimate supplementary control costs due to the large number of facilities and the lack of knowledge of current controls and configurations. One radiopharmaceutical manufacturer is estimated to have releases resulting in a dose greater than 1 mrem/yr, but is already using charcoal filters. The efficiency of this control technology can be enhanced via three methods: cooling the effluent, reducing the humidity, or decreasing the flow rate. It is crudely estimated that the increased control cost for this facility might be $350,000, which could achieve a 99 and 75 percent reduction in radioiodine and noble, gases respectively. The associated risk reduction would be from 8E-3 to 3E-3 d/yr. The second facility that is estimated to have releases resulting in doses greater than 1 mrem/yr is a sealed source manufacturer, which would require a catalytic recombiner to achieve a 99 percent reduction in emissions. The estimated cost of this control is between $1.7 and $7.0 million. This would result in a reduction of the risk by 4E-3 d/yr. However, because the doses and risks associated with facilities in this category are not accurately known, the total number of necessary controls cannot be ascertained.

11.4 Analysis of Benefits and Costs

Only two of the nine sub-categories are projected to have releases resulting in doses high enough to warrant evaluation of supplementary controls. Moreover, these sub-categories contained only a few sources which resulted in significant doses. However, this conclusion is based on incomplete data.

Table 11-2 presents the costs of the controls. The estimated benefit of supplementary controls for the facility "D" radiopharmaceutical manufacturer is 1.5E-2 d/yr, assuming a capital cost of $350,000. This translates into a net present value between $320,000 and $350,000 and an annualized cost ranging from $3,200 to $3,500.

The total number of cancer deaths averted are also presented in Table 11-2. The total number of fatal cancers averted due to supplementary controls for the Sealed Source facility "C" is estimated to be 4E-1 over the course of a century. A wide range of costs was considered since an engineering study of the specific requirements was not performed. The study that was completed gave "low-cost" and "high-cost" estimates. The net present value ranges from $1,550,000 to $7,000,000 and the annualized payment ranges from $20,000 to $70,000.

11.5 Industry Cost and Economic Impact

Industry costs and economic impact for this category can only be roughly approximated. The 6,000 facilities are not well characterized and emission data are incomplete.

Most of the sources in the several industries considered in this chapter are not likely to require supplementary controls. For the two sources that may require supplementary controls, the costs to one, Radiopharmaceutical "D", are under half a million dollars and will avert 1.5 cancer deaths per century. The cost for the other, Sealed Source "C", is over 11.5 million and will avert 0.4 cancer deaths per century.

Table 11-2 Costs and Benefits for Controls on the Two Sources for which Controls are Required

Facility	Net Social Discount Rate (%)	NPV of Control Cost ($/cent)	Cancer Deaths Averted (d/cent)
Radio-pharmaceutical "D"	0	350,000	1.5E+0
	1	346,000	1.5E+0
	5	333,000	1.5E+0
	10	318,000	1.5E+0
Sealed Source "C" low-cost	0	1,700,000	4.0E-1
	1	1,683,000	4.0E-1
	5	1,619,000	4.0E-1
	10	1,545,000	4.0E-1
Sealed Source "C" high-cost	0	7,000,000	4.0E-1
	1	6,931,000	4.0E-1
	5	6,667,000	4.0E-1
	10	6,364,000	4.0E-1

Should either of these sources be controlled, any economic effects would be localized to the firm and its immediate customers and suppliers.

As an alternative approach, a survey conducted by the Nuclear Regulatory Commission [NRC81] can be used to estimate impacts associated with regulatory options under consideration. Approximately 3,000 facilities licensed to possess radionuclides were surveyed and about half responded. Doses caused by each of these facilities were estimated using compliance procedures from [EPA89(A)]. Based on this analysis capital costs of $5 million and operating costs of $2 million/yr are estimated for a three mrem/yr standard; capital costs of $25 million and annual operating costs of $12 million/yr for a one mrem/yr standard; and capital costs of $60 million and annual operating costs of $35 million/yr for a 0.3 mrem/yr standard.

REFERENCES

AHA86	American Hospital Association, *Annual Survey of Hospitals*, Chicago: Illinois, 1986.
BAT83	Battelle, Inc., *An Economic Study of the Radionuclides Industry*, Washington, D.C., for the U.S. Nuclear Regulatory Commission, NUREG/CR-2048, 1981.
CEN81	Centaur Associates, Inc., *An Economic Study of the Radionuclides Industry*, Washington, D. C., for the U. S. Nuclear Regulatory Commission, NUREG/CR-2048, 1981.
CRC87	Council of Radiation Control Program Directors (CRCPD), Inc., *Compilation of State-by-state Low-level Radioactive Waste Information*, for U. S. Department of Energy, Frankfort: Kentucky, DOE/ID/12377, 1987.
EPA89	*Risk Assessments*, Vol. 2.
EPA89(A)	Environmental Protection Agency, *Background Information Document: Procedures Approved for Demonstrating Compliance With 40CFR Part 61, Subpart I*, January 1989.
Ma88	Manengo, J.J., et al., *Environmental Monitoring and Disposal of Radioactive Wastes from U. S. Naval Nuclear Powered Ships and Their Support Facilities 1987*, Naval Nuclear Propulsion Program, NT-88-1, Washington: D.C., 1988.
Mo88	Moriarty, M., personal communication, U. S. Nuclear Regulatory Commission, Washington: D. C., 1988.
NCR89	*Screening Techniques for Determining Compliance with Environmental Standards*, NCRP Commentary No. 3; Revision of January 1989.
NRC81	*A Survey of Radioactive Releases from By-Product Material Facilities*, J.R. Cook, U.S.N.R.C., August 1981, [NUREG-0819].
NRC88	Nuclear Regulatory Commission, *An Economic Study of the Radionuclides Industry*, Washington, D. C., 1988.

CHAPTER 12

SURFACE URANIUM MINES

12. SURFACE URANIUM MINES

12.1 Introduction and Summary

Surface uranium mines represent a depressed segment of a declining industry which serves a small number of potential customers. They face declining demand for their output and price competition from both underground mines and foreign producers. All but two of the hundreds of surface uranium mines that operated from the 1950s to the early 1980s are currently inactive.

Controls on surface mines to reduce particulate radionuclide emissions and radon fluxes consist of applying a layer of cover over the top of the closed mine area. The costs of this procedure are measured in thousands or millions of dollars per mine.

12.2 Industry Profile

12.2.1 Introduction

Surface uranium mines are a subset of the U.S. uranium mining industry. Uranium is also produced by underground mines which are discussed in Chapter 2. Uranium is used to produce electricity and nuclear weapons. Chapters 1, 3, and 4 also discuss aspects of the uranium industry. The number of active surface uranium mines has sharply declined in recent years due to competition from underground mines and foreign producers, and to declines in demand for uranium for both of its uses.

12.2.2 Demand for Uranium

Uranium is an input to two industries: nuclear power production and nuclear weapon production [EPA89]. The demand for uranium from ore for these industries is currently in decline. The demand for fuel for nuclear reactors must either be more or less constant or slightly on the increase. Since the military has made no recent purchases of uranium, their demand has neither increased or decreased.

Uranium is used as a fuel in nuclear power plants, after being milled and enriched. Although there was rapid growth in this segment of the electric power industry from the late 1950s to the early 1980s, recent years have seen a total and abrupt stop in construction of new units. The factors contributing to this decline included escalating costs, a general decline in the growth rate of the power generation industry, and increasing public concern for safety. Also, the financing and management of some plants under construction led to severe financial problems. Some plants were abandoned in mid-construction, while others were completed, but have not yet been commissioned.

The only demand for uranium by the U.S. nuclear power industry in the near future will be to fuel existing power plants including those waiting to be commissioned. This source of demand will decline as plants age and are decommissioned.

The second source of demand for uranium is the production of nuclear weapons which use uranium as an input. Currently, weapons production reactors are closed due to problems with safety and with past improper waste storage practices that have been discovered to pose a threat to nearby populations. When these plants reopen, there will be a continuous, but not very large, demand for uranium.

12.2.3 Supply of Uranium

Surface uranium mines currently operate at a small percentage of their overall capacity. (See Figure 12-1.) As recently as 1980 they produced 20.8 million pounds of U_3O_8 from 50 mines. In 1986, they produced about 2 million pounds of U_3O_8 from four mines. In 1988, there were two active surface uranium mines [EPA89]. All the mines studied in this chapter with respect to emission control are currently inactive. Some are unreclaimed and others are reclaimed. The mines studied are located in South Dakota, Wyoming, Colorado, Arizona, and Texas [EPA89]. As illustrated by Table 12-1, surface mining took place in other states as well, but not to the same extent.

A major problem facing surface uranium mines is competition from underground mines and foreign producers. Table 12-2 demonstrates that underground mining is especially dominant when prices are low, in the $30/lb. range. Table 12-3 illustrates the international competitive situation, especially for reasonably assured reserves (RAR). The U.S. is not competitive with Australia at lower price levels.

Figure 12-1: Uranium Production
U.S Open-Pit Mines and Total Output

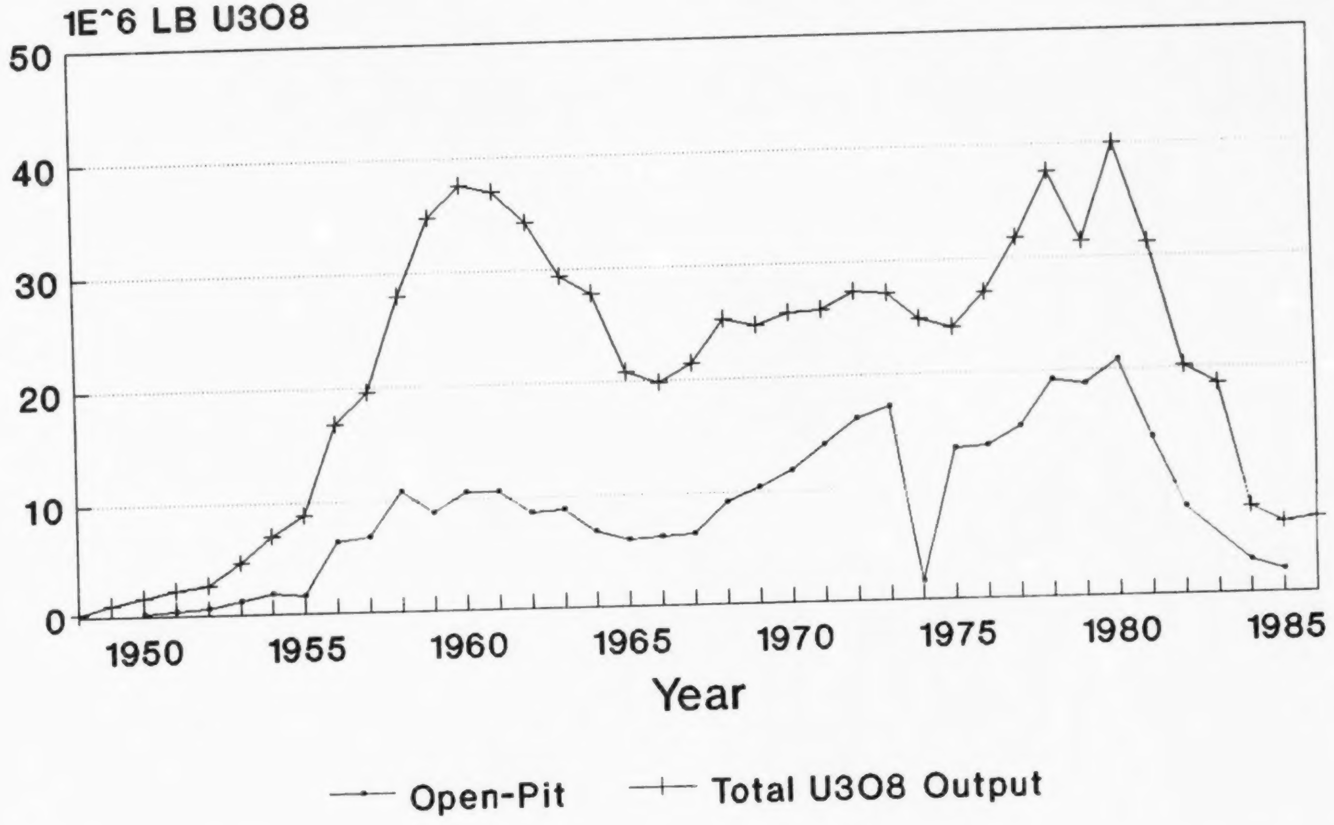


Table 12-1: Number of Significant Production Surface Uranium Mines by State.

State	Number Capable of Producing 1,000 to 100,000 T/yr	Number Capable of Producing over 100,000 T/yr
Arizona	37	1
California	1	0
Colorado	12	4
Idaho	1	0
Montana	1	0
Nevada	1	0
New Mexico	3	5
North Dakota	10	0
Oregon	1	1
South Dakota	33	2
Texas	19	25
Utah	6	0
Washington	3	2
Wyoming	66	31

Source: [EPA89]

Table 12-2: Reasonably Assured Resources by Mining Method at the End of 1986 in the U.S. (million pounds of U_3O_8).

	Forward Cost Category		
Mining Method	$30/lb	$50/lb	$100/lb
Underground mining	216	549	881
Open-pit Mining	45	326	503
In Situ Leaching	61	143	222
Others	1	18	24
Total	322	1036	1630

Source: [SC89]

Table 12-3: United States and Selected Foreign Uranium Resources as of End of 1986.

TOTAL RESERVES

Country	Reasonably Assured Resources*		Estimated Additional Resources*	
	$30/lb	$50/lb	$30/lb	$50/lb
United States	322	1036	1350	2370
Canada	416	603	268	528
Australia	1201	1347	668	998

* Million Pounds U_3O_8

Source: [SC89]

12.3 Current Emissions, Risk Levels, and Feasible Control Methods

For all regions, the total number of fatal cancers per year due to radon releases from inactive uranium surface mines is estimated to be 3E-2 and the total fatal cancers per year due to particulate emissions from inactive uranium surface mines is estimated to be 2E-2 [EPA89]. These risks are spread across a large geographic area.

Specific studies were done on actual representative mines. They considered the emissions, the lifetime risk to the most exposed individual, and the annual risk to the regional populations within 80 km. of the mine sites. The highest lifetime individual risk reported was 5E-5 [EPA89]. The highest annual regional risk was 1E-3, associated with the Wright-McCrady mine in Texas [EPA89].

The method proposed for reducing both radon and particulate emissions is to cover the sites with dirt. It was assumed that 15 cm of cover would effectively reduce particulate emissions to background levels [SC89]. The amounts of cover required to reduce radon fluxes vary, depending on the initial flux rates and the control standard. The alternative rule considered was to cover sources to limit emissions to 40 $pCi/m^2/sec$. This assumes 0.2 meters of dirt is applied to the surface of the mines. This application of dirt eliminates particulate emissions while reducing radon emissions. The capital cost for this alternative is $15 million, or $0.8 million on an annualized basis [SC89].

12.4 Analysis of Benefits

The alternative approach discussed in the preceding paragraph would reduce maximum individual risk of fatal cancer to 2E-5, while the incidence of fatal cancer to the 80 km population would fall by 2E-2 to a level of 4E-3 [SC89].

12.5 Industry Cost and Economic Impact Analysis

The risks of cancer deaths induced by surface mines emissions are relatively low, while the costs of control are in the millions of dollars. Were controls implemented, the economic effects would fall on the owners of closed mines. There are no customers of these mines to whom the owners could pass the costs of controls. The second round effects are harder to designate, since they depend on what financial entity is affected and its ability to stay in business after paying the costs. Since the owners of these mines are often large energy companies, it is unlikely that they will go out of business due to a single expenditure of 10 million dollars. Work forces will not be affected, because operations at these mines have already been curtailed.

REFERENCES

EPA89	*Risk Assessments*, Vol. 2.
SC89	SC&A, Inc., "Radiological Monitoring at Inactive Surface Uranium Mines," prepared for the U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C., February 1989.